AN INVESTIGATION INTO THE VALIDITY OF PERCENTAGE BODY FAT ESTIMATIONS BY A NEW BIOELECTRICAL IMPEDANCE ANALYSER

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ABSTRACT

This study was designed to assess the validity of a new method of estimating per cent body fat (%BF) by bioelectrical impedance (BIA). Both models of the new analyser, Tanita TBF 305 and TBF 511 were used to estimate %BF in a sample of active Caucasian adults: 16 male and 23 female. Males: mean age 45.37± 9.16 years, mean weight 62.10±8.30 kg. Females: mean age 41.96±8.01 years; mean weight 62.10±8.30kg.

The new analysers were validated against estimates of %BF by Densitometry (D), compared with sum of skinfolds (SS), BIA Bodystat 1500 (BS) and calculated %BF from BMI. Paired 't' tests were conducted on all methods and compared to D. Bias and 95% Limits of Agreement were calculated using the method of Bland and Altman.

Results showed that all methods overestimated %BF significantly in relation to D, except with BS in men. Statistical analysis using paired 't' test and the Bland & Altman method of calculating bias and 95% Limits of Agreement was TBF305 1.18 ± 7.50 %BF for men and 7.40 ± 12.84 %BF for women; TBF 511, 2.14 ± 7.54 %BF for men and 8.40 ± 11.72 %BF for women.

It was concluded that because the bias and 95% Limits of Agreement suggested that the new method will overestimate significantly in comparison to D that it could not be recommended as a valid method of estimating %BF and that its use even as a comparative measure of %BF in large epidemiological studies is limited.

Key words: per cent body fat, bioelectrical impedance, densitometry, sum of skinfolds, Tanita, Bodystat, Limits of Agreement.

This work is original and has not been previously submitted in support of a Degree, qualification or other course.

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CHAPTER 1 - INTRODUCTION

The assessment of body composition and in particular, the estimation of percentage body fat (%BF) has become of increasing interest to sport practitioners, health care professionals and the general public. In sport, particular patterns of body composition are related to success in coping with the physiological demands of the activity (Kerr, 1994). In health care, proportions of body fat can be related to disease risk and the location and extent of both sub-cutaneous and visceral, (i.e., internal) fat deposits can be significant in particular medical conditions. There is a demand for %BF estimations from the public for reasons related to perceptions of personal appearance and because of increased interest and participation in sport and fitness. The insurance market is interested in predicting risk of morbidity and mortality from health screening measures and has traditionally included assessments of body composition for this purpose (Hawes, 1996). There is therefore considerable financial motivation to develop acceptable methods of estimating %BF, particularly if they are quick and easy to use. Methods of estimating using Bioelectrical Impedance Analysis (BIA) can be employed relatively quickly and in the case of the new analysers used in this study, with the minimum of intrusion to the user. The objective researcher must, however, be concerned about the validity and reliability of the new method and about the practical and ethical implications of its use.

It is important to note that the estimation of body composition is not an exact science, as body components can only be measured *in vivo* indirectly (Katch & Katch, 1980). Direct measurement of body fat has, so far, only been done by

chemical analysis of material from cadaver dissection (Clarys, Martin, Drinkwater and Marfell-Jones, 1987). Advances in technology, for example, the use of computerised tomography (Heymsfield & Matthews, 1994), have enabled more detailed estimates to be obtained. However, most methods of estimating %BF which are accessible and affordable to sports scientists and many clinicians are still indirect methods, based on assumptions about the characteristics of the major tissue components of the body. The validity of the criterion method of estimating body density, densitometry, against which any new method has traditionally been compared, is being questioned (Hawes, 1996) as further work is done with the use of more sophisticated techniques. It is also evident that the physiological perameters which influence the measurement of body density, such as hydration levels and lung volumes, are variable over the short or long term. A validation study of a new method of estimating %BF can therefore be an opportunity to explore the wider aspects of estimating body density by traditional methods and also to consider what further work would make a useful contribution to this contentious and challenging area of study.

New methods of %BF estimation have traditionally been validated against the established criterion method, densitometry [D]: (also described as hydrostatic weighing or underwater weighing) and compared to other methods in common use: sum of skinfolds (SS), dual-X-ray absorptiometry (DXA) and infra-red interactance (NIR). These studies not only offer the opportunity to consider the validity and reliability of all the methods of estimation used, but also to develop appropriate methods of statistical analysis for validation studies (Bland & Altman, 1980; Williams & Lamb, 1996; Reilly, 1996). This study was designed to validate

two models of a new bioimpedance analyser (BIA), Tanita Models TBF 305 (T305) and TBF 511 (T511), (Tanita Corporation of America, Inc., Skokie, Illinois., U.S.) using D as the criterion method for comparison. The Tanita BIA method is different from conventional BIA because it takes measurements of electrical impedance from leg-to-leg via metal footpads on a pair of free-standing scales. The scales also measure bodyweight, and in the case of T305 which is connected to a computerised print-out, measurements of other aspects of body composition: total body water (TBW) and the estimated weight of body fat and lean body mass. A copy of the manufacturer's sales information leaflet is included in Appendix B.

In this study, three other methods of estimating %BF were used as comparisons: sum of skinfolds (SS) using Durnin & Wormersley's equations for body density (1974), a conventional BIA, i.e., hand-to-leg, BodyStat 1500 (BS) (Bodystat Ltd, Isle of Mann, U.K.) and calculation of %BF from body mass index (BMI). It should be noted that this work formed part of a larger study sponsored by the manufacturers of the new analyser to determine its validity with a particular sample of the population (Williams, Irving, Roberts & Sykes, 1997 [unpublished technical report]). The larger study pooled data from 56 physically active subjects between the ages of 21 and 61: the present work concerns results obtained from the subjects aged between 30 and 61. A sample of older active subjects was chosen because individuals with this activity profile are under-represented in the literature on body composition, so the data collected would be of particular interest. Furthermore, as they were likely to have an interest in health and fitness they

would represent a segment of the population for whom the Tanita scales were intended.

Examination of the promotional material for this BIA method, together with an inspection of the Tanita website on the Internet (http://www.tanita.com), show that the manufacturer's main interest is in the sale of a wide range of medical and domestic weight scales, several models displaying %body fat and/or BMI data. The Tanita TBF305 appears to be designed for sale to health clubs: it is described as a "profitable opportunity" for business within this market.

Four studies which have investigated the validity of the new analysers were selectively published in a Report from the 1994 International Congress on Obesity supplied by the manufacturers. A study by Nunez, Gallagher, Visser, Pi-Sunyer, Wang and Heymsfield established validity with densitometry and also compared data obtained from DXA, conventional BIA and SS. However, validity was established, as in the other three studies, by reporting a significant Pearson Product Moment Correlation Coefficient, 'r', between methods. This statistical test is now considered inappropriate for validation studies (Neville, 1996). Sakamoto, Miura, Yamaguchi, Ohno and Ikeda, whose laboratory designed the Tanita BIA method, reported a correlation-based study comparing the Tanita method with DXA and BMI. Again, significant values of 'r' were reported, and the method was described as "very useful" compared with DXA. A more recent study by Hainer, Kunesova, Parkzkova, Stich, Horejs and Muller (1995) used CT scanning as an additional comparison but quantified fat estimates by weight rather than as a percentage.

It is therefore evident that there was a need for a carefully planned and conducted validation study of this method of BIA %BF estimation, using appropriate comparative methods and an acceptable form of statistical analysis.

CHAPTER 2 - METHODOLOGY

2.0 GENERAL CONSIDERATIONS

The plans for this study were submitted in June 1996 as a research proposal and were approved by the University College Chester Ethics Committee. The research design was based on a previous BIA validation study at the same institution (Williams, 1995); this design was also used in study for the technical report mentioned earlier, which was written for the manufacturers of the Tanita BIA analysers. Procedural reliability for the research protocols, excluding the Tanita BIA method, had been established in the study by Williams (1995) by analysis of repeated measures of each test used, giving a mean difference between measurement occasions of approximately 0.0%BF. Williams' (1995) calculation of coefficient of repeatability (Bland and Altman, 1986) gave variation limits of 2.6%BF for densitometry, 0.5%BF for sum of skinfolds and 2.7%BF for Bodystat within 95% of test sessions, comparable with similar studies (Lohman, 1992). For this study, test-retest measurements of %BF estimations using T305 and T511, gave a mean difference between estimations by T305 of 3.17%BF and by T511 of 3.0%BF for male subjects and of 0.55 and 1.54 for females. The procedure for the test-retest measurement was to repeat the %BF readings on the T305 and T511 between 24 hours and 14 days of the original testing. The mean difference between measurements was not statistically significant ($p<0.05$). It was found that immediately repeated measurements taken within 10 minutes during the pilot test sessions gave estimations of within 1%BF for both analysers in both male and female subjects.

Table 1: Analysis of test-retest %BF estimations: T305 and T511

using paired 't'test

	Males (n = 6)		Females (n = 9)	
	Mean Diff.	'p'	Mean Diff.	'p'
T305	3.17	0.212	0.55	0.821
T511	3.00	0.268	1.44	0.555

Mean Diff = Mean Difference in %BF of test values between measurement occasions. $p>0.05$ indicates that mean differences in %BF between measurement occasions are not significant.

The measurement procedures were conducted three times with volunteers prior to testing to establish timing, correct procedures, calculations and skills. The author also acted as a volunteer in order to appreciate the subjects' experience of being tested.

2.1 SUBJECTS

Thirty-nine Caucasian subjects were volunteered to this study. The characteristics of the sample are summarised in Table 2.

Table 2: Summary of subjects' characteristics

	Males (n = 16)	Females (n = 23)
AGE(range 30 - 61 years)	45.37 ± 9.16	41.96 ± 8.01
WEIGHT (kg)	73.47 ± 7.56	62.1 ± 8.30
HEIGHT (m)	1.73 ± 0.39	1.65 ± 0.68

All subjects completed a consent form prior to testing. Age criteria were set (30 - 61 years), to establish a particular sample of the adult population. The following conditions were required to be met to ensure that subjects were physically active and were all at approximately the same level of hydration at the time of testing. These conditions therefore limited the variability within the sample in terms of age, activity level and state of hydration.

Prescribed activity level: > 4 x 20 minutes vigorous aerobic exercise each week for the past 4 weeks

Activity levels were established by means of a self-reporting questionnaire based on the Allied Dunbar National Fitness Survey (Activity and Health Research, 1994). The conditions which had to be met prior to testing were:

- no caffeine or alcohol for 24 hours
- no exercise for 12 hours
- no eating or drinking for 4 hours

2.2 DESIGN

A repeated measures design was used for this study. D was used as the criterion method against which other methods of estimating %BF were compared: BS, SS and T305 and T511. Calculation of %BF from BMI was subsequently calculated (Deurenberg, Westsrate and Seidell, 1991) to serve as a further estimate. In a true validation study where the criterion method is accepted as the "gold standard", the null hypothesis tested is that there is no relationship between the new method of measurement and the criterion. The concern about D as a criterion method for

estimating %BF will be considered in the Discussion. Suitable tests for statistical analysis and for initial comparisons of results were therefore chosen for the validation study with these limitations in mind. This study, therefore, was designed to provide a validation of the new BIA method and others against D but also to attempt to analyse the limitations in all the methods of estimating %BF used.

2.3 PROCEDURES

Subjects were given appointments for testing, which took between 75 and 90 minutes for each subject; no more than three subjects were tested on any one day. %BF calculations were, as far as possible, made during the testing procedure so that subjects were informed of their %BF estimates. Information about body composition and the reasons for the various procedures were given to the subjects throughout their appointment, as well as an interpretation of their %BF measurements.

Tests were administered in a specific order rather than randomly. This was for two reasons. For D, the subject is totally submerged in water so it was inappropriate to conduct this test prior to the other estimates as water on the skin surface would have affected the validity of the later estimates. Secondly, it was considered important that the simplest tests, which also involved the least personal intrusion, should be conducted first, followed by the other tests in order of technical complexity. Thus the order of testing was: T305, T511, BS, SS, D.

For %BF estimations with T305 and T511, weight and impedance (T305 only) were also recorded. This was followed by estimations using BS, following

the manufacturer's instructions for positioning the subject and the placement of electrodes. %BF and impedance were recorded. SS measurements were taken using the sum of 4 sites: biceps, triceps, subscapular and suprailliac, with the average of 3 measurements at each site recorded. Guidance for site identification was given by Lohman et al (1995). Calculation of %BF from SS was made by establishing body density (D_B) according to Durnin & Womersley (1974) and %BF from Siri, (1961):

$$D_B = c - (m \times \log SUM)$$

where c and m are constants according to sex and age and SUM = sum of four skinfold measurements in mm.

$$\%BF = \frac{495}{D_B} - 495$$

Vital Capacity (VC) was measured using a Vitalograph (Vitalograph Ltd., Buckingham, U.K.). This parameter was estimated in order to use an appropriate volume of oxygen in the subsequent Residual Volume (RV) estimations. Subjects showered before entering the hydrostatic weighing tank for RV estimates and underwater weighing. RV estimates were made with the subject immersed to the neck to allow for the compressive effect of water pressure on lung volumes (Latin and Ruhling, 1986), using the simplified oxygen dilution procedure described by Wilmore (1980). This was calculated using data from oxygen and carbon dioxide gas analysis of a measured quantity of oxygen, which the subject rebreathed during a specific number of deep breaths. The final RV estimate was taken as the average of 2 trials which agreed to within 100ml. RV was estimated using the following equation:

$$RV = \frac{VO_2 \times (100\% - [\%O_2 + \%CO_2])/100}{0.798 - (100\% - [\%O_2 + \%CO_2])/100} - DS \times BTPS$$

Where VO_2 = volume of oxygen in rebreathing bag

DS = Dead space from mouthpiece to valve in apparatus

BTPS = correction factor dependent on room temperature and pressure

DS had been measured during the protocol design by filling the dead space with water and recording the volume.

Subjects were then weighed, totally submerged underwater at maximum expiration, to the nearest 0.10 kg and with asymptote assumed following 3 consecutive readings within 0.10 kg. %BF was calculated from D using the following calculations, which firstly determine the volume of the body, then body density and finally %BF according to Siri (1961):

$$\text{Volume of body } (V_B) = \frac{(BWt_A - Bwt_W)}{D_W} - RV + V_{GI}$$

Where BWt_A = body weight in air

BWt_W = body weight in water

D_W = density of water

V_{GI} = volume of gas in gastrointestinal tract (assumed 0.1l)

$$\text{Body density } B_D = \frac{BWt_A}{V_B}$$

$$\%BF\ (Siri) = \frac{495}{B_D} - 450$$

Following the testing procedures, subjects were reminded to drink and eat a snack: this was assumed to be particularly important for older subjects whose carbohydrate metabolism might not have compensated to the 4 hour fast as easily as a younger individual. An appointment for a retest of the T305 and T511 methods was arranged where possible, under the same conditions as for the full test procedures.

Subsequent calculations for %BF from BMI were made according to the following equations:

$$BMI = \text{weight in kg}/(\text{height in m})$$

$$\%BF = -5.4(BMI) + 0.23(age) - 10.8(sex)$$

Where 1 = male; 0 = female (Deurenberg, Weststrake and Seidell, 1991)

2.3 STATISTICAL ANALYSIS

To assess the validity and reliability of %BF estimations by the Tanita BIA method, the data from this study was analysed using a range of statistical procedures. This was also done in an attempt to expand on the discussion of appropriate statistical tests for validation studies: Bland & Altman, (1983); Williams & Lamb, (1996); Nevill (1996); Bartlett (1997). The Pearson Product Moment Correlation Coefficient, 'r', between methods of estimating %BF was calculated as a means of demonstrating the limitations of this statistical relationship between variables when compared to subsequent analysis of mean differences between estimates. Mean

differences for the same pairs of estimates (i.e., %BF by D compared to other %BF estimates) were compared using paired 't' tests. The condition for using the paired 't' test is that a normal distribution of results has been obtained (sample histograms demonstrating this appear in Appendix C) and also that, in the case of a validation study, that there is a criterion method for comparison. Here, this would show whether or not there was a significant difference between %BF estimates by D when compared to estimates by the other methods. To examine the relationship further, Bland & Altman plots were generated to display the results within 95% Limits of Agreement (L of A), i.e., $\approx$ 2SD above and below the bias (mean difference) between each pair of methods. However, as argued by Bland & Altman (1986), in the case of a validation study, the researcher needs to use their professional judgement to assess whether the range of measurements obtained within the 95% L of A is acceptable for validation of the new method. Data from estimates of RV (see Appendix C) were analysed using one-way ANOVA tests to determine whether significant differences occurred between estimates grouped by age. The one-way ANOVA was used in order to compare the mean RV of 3 age groups simultaneously. A post-hoc test (Tukey's HSD test) was used where significant correlation occurred.

Data from all the measurements was entered onto a spreadsheet and analysed using SPSS version 6 (SPSS Inc., [1983], Chicago). A summary of the results follows, grouped according to the statistical tests involved; additional results, test outputs and graphical displays are contained in Appendix C.

CHAPTER 3 - RESULTS

Results are reported for male and female subjects separately because combined figures obscured observed gender differences within %BF estimates for each method. This also applies to the results of investigating subjects' VC and RV, which are reported subsequently. Note: full data sets were obtained for all subjects except for one female subjects whose %BF by T305, T511 and by BS were deemed invalid because the measurement of her height was entered incorrectly into the equipment. The number of female subjects for each set of results (n) is described accordingly.

3.1 %BF ESTIMATIONS - MEAN VALUES

Table 3: Mean values and SD of %BF estimates by different methods.

	Males (n = 16)	Females (n = 23/22*)
Densitometry (D)	16.54 ± 4.89	21.31 ± 7.63
Bodystat 1500 (BS)*	18.04 ± 4.32	25.73 ±5.18
Sum of Skinfolds (SS)	20.91 ± 4.81	29.34 ± 5.83
Tanita 305 (T305)*	18.31 ± 4.96	28.45 ± 5.07
Tanita 511 (T511)*	18.69 ± 5.00	29.32 ± 5.03
BMI	23.67 ± 3.66	30.97 ± 3.98

* indicates 22 female subjects tested using this method.

Table 3 shows mean %BF by D first, the criterion method. Mean values for the other methods of estimation used enable comparison between mean values for D

and each method, together with the range of values obtained for male and female subjects. These differences are demonstrated in more detail in Table 4 below.

3.2 %BF: CORRELATION AND MEAN DIFFERENCES BETWEEN METHODS

Table 4 shows the Pearson Product Moment Correlation Coefficient, 'r', between the %BF by D and the each of the other methods of estimating %BF, and between %BF by BMI and D, T305 and T511. For comparison, the mean difference and one SD (see 4.3 Bland & Altman plots) of the mean difference between each pair of estimates is also shown, together with the 2-tailed significance of the mean difference, 'p'. These results were obtained by running the three separate tests on the data. However, all these statistics appear on the SPSS output for a paired 't' test on the paired data sets. Histograms of each test showed a normal distribution in the values of paired differences. Table 4 shows that the mean difference between D and the other methods ranges from +1.15%BF with BS to +7.10%BF with BMI in male subjects and in female subjects from +4.80%BF with BS to +9.70%BF with BMI. When the Tanita methods were compared to BMI, BMI was found to exceed estimates from T305 and T511 by +5.40 %BF and +5.00 %BF for male subjects and +2.20 %BF and +1.30%BF for females respectively. The standard deviation of the mean difference between each pair of methods varied between 3.18%BF (BMI with T511) and 4.89%BF (D with BS) for male subjects and 4.43%BF (BMI with T511) and 7.76%BF (D with BMI) for female subjects.

Table 4: Differences between methods of estimating %BF

	Males (n = 16)				Females (n = 23/22*)			
Methods	'r'	MD	'p'	SD	'r'	MD	'p'	SD
D/BS*	0.44	1.15	0.238	4.89	0.58	-4.80	0.002	6.20
D/SS	0.59	4.40	0.001	4.39	0.50	8.00	0.000	6.52
D/T305*	0.71	1.77	0.078	3.75	0.54	7.50	0.000	6.42
D/T511*	0.71	2.14	0.038	3.77	0.63	8.40	0.000	5.86
D/BMI	0.57	7.10	0.000	4.12	0.23	9.70	0.000	7.76
BMI/T305*	0.77	5.40	0.000	3.18	0.45	2.20	0.042	4.76
BMI/511*	0.77	5.00	0.000	3.16	0.52	1.30	0.001	4.43

'r' = Pearson Product Correlation Coefficient between estimates from individual methods.

MD = mean difference of estimates between pairs of methods; 'p' is the level of significance for this difference; SD = standard deviation of the mean difference between methods.

* = 22 female subjects tested using this method

Results from the paired 't' tests show that the paired differences between the mean values for male subjects were significant at $p<0.05$ except for D with BS and T305. For female subjects, the paired difference between %BF estimates from all the paired tests were significantly different at $p<0.05$.

Pearson's Product Moment Correlation Coefficient, however, had shown that there was a significant correlation, 'r', between the methods for male subjects ($p<0.05$) except between D and BS. For female subjects, the correlation was significant except for estimates for D with BMI ($p <0.05$).

3.3 BLAND & ALTMAN PLOTS

Bland and Altman's (1986) method of presenting the calculation of the bias between methods and the paired scores within 95% L of A was used to demonstrate the results of the paired 't' test in more detail. To calculate the bias and 95% L of A for this method, it was necessary to the calculate the mean and the difference between the two tests being compared, together with ±2SD of the mean difference. These calculations were made and listed as separate variables included in the raw data (Appendix C). If, however, a paired 't' test is also used on the same data, these calculations appear on the test output. Relevant examples of Bland & Altman plots from this data appear in Chapter 4; a summary of the calculations of the bias and 95% L of A for each pair of methods appears below in Table 5. The figures in the table should be interpreted as follows, using the comparison between D and T305 as an example:

"Estimations of %BF using T305 with male subjects showed a bias of 1.15%BF when compared to estimates from D. Within 95% L of A, estimates of %BF by T305 will come within 9.78%BF of the bias."

Thus the maximum difference in %BF between D and BS for males in this sample, using 95%L of A, could be (1.15 + 9.78) = +10.93%BF. This shows that even though there was no statistically significant difference between the mean values for %BF estimation by D and BS, there could still be an unacceptable difference between the %BF estimates made by the two methods.

Table 5: Bias ±2SD between each pair of %BF estimation methods

	Males (n = 16)		Females (n = 23/22*)	
Methods	Bias	95% L of A	Bias	95% L of A
D/BS*	- 1.15	±9.78	4.82	±12.40
D/SS	- 4.40	±8.78	- 8.03	±13.04
D/T305*	- 1.18	±7.50	- 7.40	±12.84
D/T511*	- 2.14	±7.54	- 8.40	±11.72
D/BMI	- 7.13	±8.24	- 9.66	± 15.52
BMI/T305*	5.40	±6.36	2.20	± 9.52
BMI/T511*	5.00	±6.32	1.33	± 8.86

* = 22 female subjects tested using this method.

Bias = +ve mean difference between methods; first method listed is the "criterion" against which the second method is compared.

3.4 24 HOUR - TWO WEEK TEST- RETEST ON T305 & T511

Results from the test-retest procedure were given in Table 1 above. Using a paired 't' test, each pair of test-retest values were found not to be significantly different for male or female subjects ($p>0.05$). However, there was a noticeable difference in magnitude between the test and retest values for male subjects with estimates made with T305 and T511 (+3.17%BF and +3.00%BF respectively).

3.5 ESTIMATION OF %BF BY DENSITOMETRY

Estimating %BF by D involved collecting data from several procedures which are conducted in a particular sequence (see Appendix B for detailed description). The underwater weighing procedure gave data which was used in the calculation of body density and, subsequently, the estimation of %BF.

CHAPTER 4 - DISCUSSION

4.0 VALIDATION OF METHODS

The results from this study prompt the discussion of several matters of critical importance in investigations into body composition analysis, the principles of which are considered in detail in Appendix A. It is also particularly appropriate to consider the suitability the term "validation" study, since it implies that the criterion method is a true measure of the variable of interest, %BF. D, the criterion method used, is an indirect method, via a calculation of body density, of **estimating** %BF. If this limitation is accepted, because of the absence of alternative criterion methods that could actually measure %BF, then it has been shown from the results of this study, that not only the Tanita BIA method but also the other methods used are unacceptable alternatives to D because of the extent to which they overestimate %BF for this sample. However, it is also clear from the results that there are physiological variables which may have an effect on estimates of %BF for individuals within the population sampled, and which may particularly influence %BF estimates by D and by the Tanita BIA method.

4.1 DESCRIPTIVE DATA: SUBJECT CHARACTERISTICS AND RANGE OF %BF ESTIMATES

The age range of the subjects in this study (30 -61 years) covers a period in life during which the recognised sub-divisions of body tissue usually alter in their relative proportions: this includes body fat which generally increases and accumulates in particular body sites according to gender (Bemben et al, 1994; Pollock, Hickman, Kendrick, Jackson, Linnerud and Dawson, 1976). The 39

subjects who took part in this study were all physically active (Activity & Health Research, 1994). This condition reduced variability to ensure a more homogeneous sample. However, although this condition required that each subject had taken part in at least (4 x 20 minutes) vigorous exercise in each of the 4 weeks preceding the study, there was a range in the number of 20 minutes sessions above this level: from 4 x 20minutes to 13 x 20 minutes per week. The activity levels of the sample may have mediated the effect of age on body density, which has been reported to decline by as much as 30% between the ages of 30 and 70 in men (Bemben, Massey, Bemben, Boileau and Misner, 1994) and in also in women, due to reduced bone density and muscle strength and increased fat mass. It would therefore be expected that data from estimates of %BF for this sample would demonstrate some degree of variance (shown in the SD of the mean values for each method) but that this would be in proportion to, or perhaps slightly less than, the expected average change in %BF for men and women during this phase of life. In addition, for this sample it would be expected that %BF would increase slightly with age for both men and women. Despite the relatively small sample size, both these latter assumptions are supported by the data: for each method of %BF estimation, the SD of the measure is between 4% and 5% for male subjects and between 5% and 6% for women, except in the case of D, where estimates vary by ±7.63%. Data plotted as bar charts show that %BF increased with age (see sample in Appendix C). Subsequent calculations for %BF estimates from BMI show a reduced spread of estimates: between 3% and 4% for both male and female subjects. This agrees with work done on %BF predictions from BMI which tends to give higher estimates than other predictive methods(Webber, Donaldson, Allison

and MacDonald, 1994)) but, in this study, shows less variation according to age compared to other methods. Excluding BMI, the range of mean %BF estimations for both men and women are within the normal range for an active sample of this age, i.e., from 16.54% to 20.91% for men and 21.31% to 29.34% for women, although clearly the range of estimates is greater for the females in the sample.

It is therefore concluded that the mean values of each method of estimating of %BF demonstrate the expected increase in %BF with increasing age and that this is more noticeable in female subjects. It is suggested that the difference in mean values is due to the different principles underlying the calculation of the estimates for each method, and that the different range of estimates within each method reflects the limitations in the prediction equations which generate these estimates.

4.2 VARIATION IN ESTIMATED %BF BETWEEN METHODS

The mean value of estimates from D were the lowest for men (16.54%BF), followed in ascending order by BS, T305, T511 and then SS (20.91%BF) (Table 2). In female subjects, D again gave the lowest estimate (21.31%BF), followed by BS, T305, SS and then, almost identical at (+0.02%BF compared to SS), T511. However, the mean value of SS estimates was only 0.02% less than T511. When the mean differences between the methods were compared using the a paired 't' test gave an analysis of the relationship between D and the other methods of %BF estimation. The null hypothesis for the 't' test, H_o, is that there is no significant difference between the mean values for each set of compared measurements. The 'p' value for each test gives the level of significance for the difference between the means of each pair. The smaller the 'p' value reported, the more significant is the

difference between the tests. The results show that at $p<0.05$, the difference was significant beyond the 5% level for all pairs of methods, except for between the estimates from D with BS and T305 in male subjects.

The Pearson Product Moment Correlation Coefficient, 'r', was also reported between the pairs of methods in Table 4. The weakness of 'r' as a determinant of the strength of a relationship is clearly shown by observing the summarised results in Table 3 and then comparing them with the reported 'r' and 'p' values for each method paired with D or BMI in Table 4. Whilst none of the correlations are "perfect" i.e., close to $\pm$ 1, they are significant at $p<0.05$ for all pairs of estimates in male subjects except for the pair which, paradoxically, have the closest agreement: D with BS. For female subjects, the correlation was significant at $p<0.05$ except for D with BMI. At the lower probability of $p<0.01$, the correlation for all pairs of methods was weaker, but not always insignificant.

The results of the paired 't' test confirm what was indicated in the comparison of mean values of estimated %BF for each method: that the %BF estimates from D compared to most of the other methods were significantly lower for both male and female subjects in this study. Further analysis was needed to investigate the relationship between D and BS and D and T305 where a weak relationship between the methods was indicated by the paired 't' test.

To increase the power of the paired 't' test, significance of the relationship at $p<0.01$ can be examined, i.e. beyond the 1% level. This showed that, in addition to the pairs identified at $p<0.05$, estimates from D with T511 in men and those from BMI with T305 in women were not significantly different. Increased power in a statistical test is generally considered to be useful because it reinforces the

conclusion demonstrated by the test: in this case whether or not there is a significant difference between the mean values for 2 methods of estimating %BF. However, it appears that increasing the power to $p<0.01$ in not helpful in this particular analysis, because it suggests that there are fewer pairs of methods with significant differences between their means. This would be an advantage if the initial exploration of the data supported this hypothesis but it does not. Knowledge and understanding of levels of acceptable agreement between methods of estimating %BF suggests that the mean differences of all the paired comparisons are unacceptably high. The use of the paired 't' test has therefore disproved the significance of the relationships noted by the Pearson correlation. Increasing the power of the 't' test by specifying a higher confidence interval is not advantageous in this case. However, the few outlying data values may have reduced the value of **t,** and therefore increase the probability of rejecting the null hypothesis at the higher confidence interval. If these outliers had been removed, the weak relationships between further pairs of tests at the higher confidence interval might not have been evident.

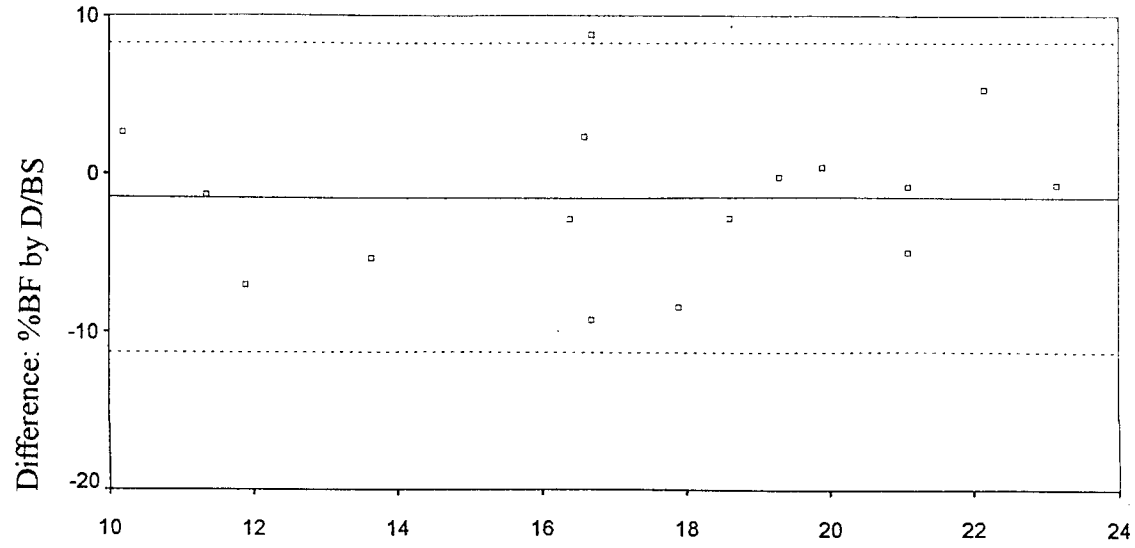
For a validation study of this type, where relatively small differences in measurements are significant for deciding whether another method is an acceptable alternative, the "mean difference" statistic reported in the paired 't' test is of greatest use. It is this statistic which forms the basis of the "Bias ± 2SD" in the Bland and Altman Plot.

4.3 STATISTICAL ANALYSIS USING THE BLAND & ALTMAN PLOT

Bland and Altman first published an account of their method of reporting data from comparisons between two methods of measurement in the *Statistician* (Bland and Altman, 1983). This has been followed by articles by the same authors in the *Lancet* (1986) and in the *International Journal of Epidemiology* (1995) to explain the methodology for other disciplines. Their method is now widely adopted in medical and veterinary studies which compare two methods of measurement; recent editorial support in the *Journal of Sports Science* (Neville, 1996) advocates its wider use in this discipline also. It should be noted, however, that much of the support for the method of Bland and Altman arises from the rejection of Pearson Product Moment Correlation as the correct statistic to report in studies of this kind. It must also be remembered that Bland and Altman's analytical procedure must be referred to as a "method" rather than a statistical "test" because it does not report any values for correlation between the two methods used. The method is a graphical technique for displaying the mean difference, or bias, between the two tests and plotting paired results from the tests within 95% L of A. It is the researcher's responsibility to assess whether (a) the bias between the methods is acceptable and then (b) if the spread of paired results occurs within an acceptable range of the bias (Bland and Altman, 1986). The pattern observed in the plot of these results may also indicate other relationships between the data from the two methods, e.g., increased differences of magnitude between test results at higher values. It has already been stated that calculations for the plots can be obtained from a paired 't' test so it is important to consider whether there is any advantage in using the Bland and Altman Plot in addition to, or as a substitute for the former

test. Part of the difficulty in the choice of an appropriate test arises from the fact that there does not appear to be a single test which is completely satisfactory for assessing the agreement between two methods of measurement. This is particularly true in the case of this study and others, where the method used as a criterion, D, is clearly not an absolute measure of the parameter of concern: %BF. For the purposes of this Discussion, the use of Bland and Altman Plots to analyse the data collected from this study is examined below.

Four of the paired comparisons with Bland and Altman Plots are discussed here. These particular plots have been chosen to illustrate both the use and the limitations of the method for this study. Figure 1 (a) shows differences in the bias between D and BS for male subjects, one of the two pairs of comparisons where the mean differences from the paired 't' test were not significantly different at $p<0.05$. However, paired scores above and below the bias are widely spread, and the difference in %BF between the bias and 95% L of A, $\pm$ 4.98%BF, is considered unacceptable for a practical assessment of %BF. Figure 1(b) shows the plot for D with SS for male subjects, where the effect of 95% L of A on an already unacceptably large bias is demonstrated. Figure 2 shows the plots for two pairs of measures for female subjects. 2(a) shows D with T305 and 2(b), BMI with T305. The plots illustrate a slightly different spread of paired measurements about the bias from the data in Figure 1, particularly in 1(b), where the paired data are clustered more closely around the bias. Again, the bias is unacceptably high. Since these plots utilise 95% L of A it is inevitable that most of the paired measurements will occur between the bias $\pm$ 2SD. Similar results were observed in the plots from the other paired comparisons.



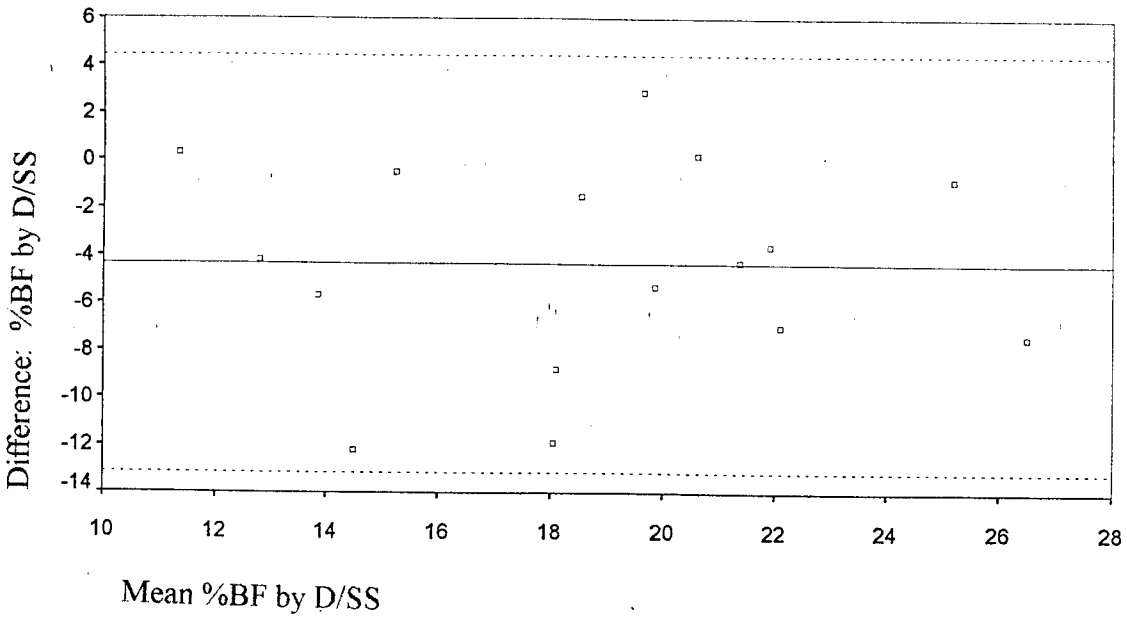
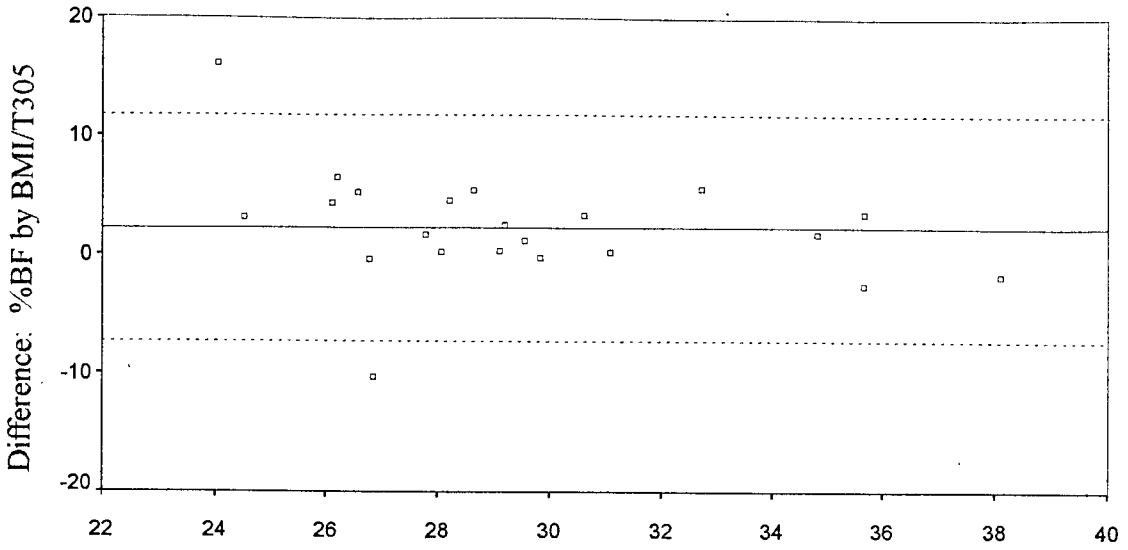


Figure 1: Sample Bland & Altman Plots: male subjects.
(a): Bias (1.15) & 95% L ofA (±9.78) for D with BS.
(b): Bias (4.40) & 95%L of A (±8.78) for D with SS.

Notes: Bias represented by solid line; L of A by broken lines.
Units: y-axis = %BF



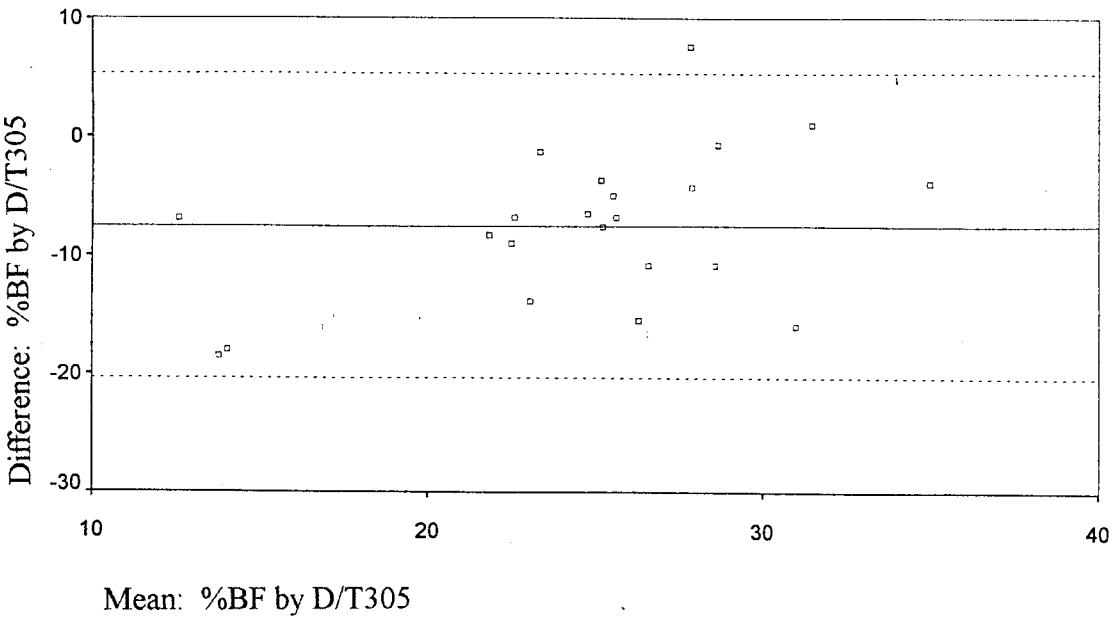


Figure 2: Sample Bland and Altman Plots: female subjects.
(a): Bias (2.20) and 95% L of A (±9.52) for BMI with T305.
(b): Bias (.7.40) and 95% L of A (±12.84) for D with T305.

Notes: Bias represented by solid line: 95% L of A by broken lines.
Units: y-axis = %BF

The Bland and Altman method of showing both the bias and the spread of paired values within 95% L of A has confirmed that for both pairs of methods shown to have weakly related mean differences in the paired 't' test, the magnitude of the values either side of the mean difference indicates that %BF estimates from these methods, BS and T305, cannot be considered as valid substitutes for D with this population.

The statistical analysis for these results appears to suggest that both a paired 't' test and a Bland and Altman plot should be conducted on a repeated measures study of this nature. The paired 't' test is important because it gives a value for the correlation for the difference between the mean of the two methods being compared. The Bland and Altman plot is useful to examine the pattern of paired scores around the bias. For many measurement comparisons, the 95% L of A will be far too broad: this can be assessed from the paired 't' test because it will be ±2SD of the mean difference. By considering the SD in the units being measured, the researcher can decide whether the new method agrees sufficiently with the criterion for validity to be accepted. It could be argued that if the mean difference (bias) and SD are outside acceptable limits, that there is no need to proceed with a Bland and Altman Plot, or that it is unnecessary because the statistics are already reported in the paired 't' test. However, the separate calculation for the Bland and Altman plot does give a graphical representation of the results of the comparison, which can be very helpful for interpretation, particularly if there is good agreement between the methods. The paired 't' test can only describe the range of the paired measurements and not the spread.

4.4 RELATIONSHIPS BETWEEN DIFFERENT METHODS OF ESTIMATING %BF

It is clear from the statistical analysis of these results that there was some agreement between the "criterion" method, D, and BS and T305 for male subjects, and no agreement between D and the all of the methods used for comparison in female subjects. Even in the cases of statistical agreement, the range of values reported about the mean difference between methods was unacceptably high (see 3.3 above). This section of the Discussion puts forward possible explanations for these differences between methods.

4.5. PROCEDURAL ACCURACY

The detailed description of the methodology (Appendix B) shows that procedures for recording data were carefully followed in this study. In addition, the timescale for the data collection stage allowed time for the testing procedure to be conducted in a thorough manner, and there was good support for the researcher from supervisory and technical staff. Subject compliance has to be considered, particularly in relation to the most complicated and least comfortable procedure, D, and with the associated estimation of RV by oxygen dilution. Error here usually results from subjects being unable to attain maximum expiration when submerged, but in this case, because body density is thus reduced, estimations of %BF are increased. This was not evident in the relatively low estimates of %BF from D in this study. Another possibility for technical error is Wilmore's simplified method of estimating RV from oxygen dilution. Again, this had been thoroughly practised beforehand and the possibilities for error mentioned in the

literature noted. Ten successive estimates of RV were conducted on one subject (see Appendices A & B) to examine the effect of the procedure on RV estimates and it was observed that there was no effect on estimated RV until the procedure had been repeated 8 times. Since only one subject in this study needed as many as five trials, this source of error is not a consideration.

The description of the procedures adopted for both of the BIA methods and SS will show that these measurements too, were taken with as much accuracy as possible, following manufacturer's instructions and recommendations from the relevant literature. It therefore seems probable that the differences between methods employed in this study arose because of the way in which each method estimates %BF.

4.6 %BF ESTIMATIONS WITH ACTIVE ADULT MALES AND FEMALES

The differences between methods demonstrated in this study, which are more noticeable amongst female subjects than male, may result from fewer studies having been done on a samples of older active females, and thus their particular characteristics of body composition not accounted for in research or prediction equations. In common with many areas of physiological research, most studies of body composition are conducted on samples of young male and female subjects; athletes (particularly male athletes) and those with specific medical conditions with wide ranges of %BF from the obese to the anorexic. This leaves a gap in knowledge about the body composition of relatively active and relatively inactive but non-obese older men and women, children and adolescents. In relation to the

SS and BIA methods used in this study, it may be that the prediction equations used were inappropriate for this particular sample.

Durnin and Wormesley's equation to predict body density does have built in constants for sex and age but this may not be sufficiently sensitive to account for the body composition of active older adults: hence, perhaps, its position as the highest estimation of %BF in this sample, apart from BMI, for both men and women. Similarly, although BS has an "activity level" selection for computing its estimates, it is known to make little difference to the final estimate (Williams, 1996, personal communication). BS did, however, come closest to D in its %BF estimates for both male and female subjects.

4.7 TANITA TBF 305 AND TBF511

The results from Tanita TBF 305 and TBF 511 analyser/scales will now be discussed in more detail. Like BS, these scales estimate %BF by bioimpedance, the opposition to the flow of an electric current through the body fluids. The accuracy of this method is dependent on three main factors: the correct positioning of the electrodes, the hydration state of the subject and the suitability of the prediction equation. The equation may predict a more realistic estimate of %BF if the proportional contribution of the measure of reactance is altered and/or more variables incorporated in the calculation. In the case of both BS and T305, height, weight, age, sex and activity level are incorporated into the equipment before the estimate of %BF is made. In the case of T511, height, weight, age and sex are used. T305 has two activity levels to choose from, "athletic" and "standard". Since the researcher was advised that the "athletic" mode had been calibrated using impedance readings and physical characteristics from a sample of

elite Japanese athletes (Tanita U.K. Limited, personal communication, 1996), it seemed reasonable to choose the "standard" setting for this sample. Further work would be required to discover if the %BF estimates would have been closer to D for this sample had the "athletic" mode been chosen. Presumably this would assume a greater density of fat-free mass in the body of the subjects being tested. Unfortunately, the prediction equation utilised by the manufacturer is not available, so it is not possible to know exactly how %BF is predicted by this method. Heymsfield et al (1994) who evaluated the T305 found that although impedance readings were similar to those obtained from arm-to-leg BIA methods, significant variation occurred between T305 and conventional BIA, DXA and D. However, although correlations were reported for these relationships, there was no quantification in terms of %BF. The reported error between methods was attributed to the diverse sample used for data collection. Despite this, Heymsfield concludes that this method has potential for large scale body composition studies where a shortage of technical staff may limit the use of conventional BIA. The study published by Hainer et al (1995) used comparisons between methods but quantified fat by weight rather than as a percentage of total body composition. They considered the Tanita method as valid because of high correlation with data from D, SS and CT scanning, but as shown in this study, relationships between methods using this statistic may be spurious.

It is likely that the error in estimating %BF with the Tanita BIA method results from the principles on which estimates are predicted by this method. Figure 3, adapted from Kushner (1992) in Heyward and Stolarczyk (1996) illustrates the

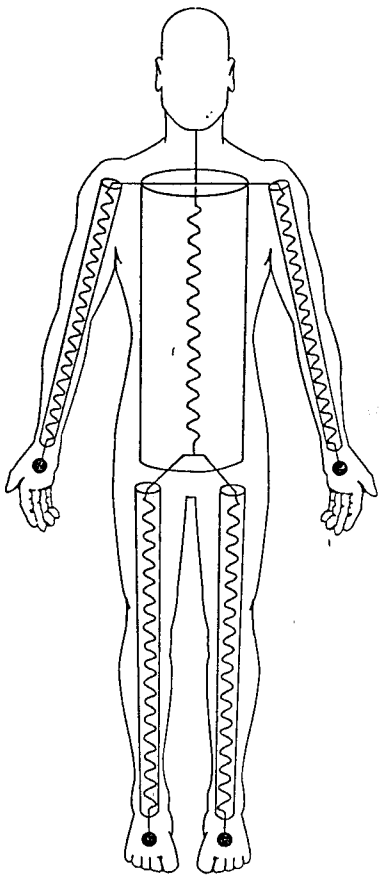


Figure 3: Pathways for conventional bi-polar BIA estimation of %BF.
Source: Kushner (1992) in Heyward and Stolarczyk (1996).

This diagram illustrates in very simple form, the routes an electric current could take in the body, dependant on the positioning of the electrodes. Foot-to-hand BIA measures impedance through more body segments than foot-to-foot BIA.

Note: the electric current will travel by the shortest route. Diagram also shows how the body should be segmented for analysis by BIA (See Appendix A).

difficulty in predicting total body fat by any single-frequency, bi-polar BIA method. The small electric current which flows across the electrodes, placed hand-to-foot in BS, or foot-to-foot as in T305 and T511 will inevitably take the shortest route between the two points. The impedance to the current, together with any variables that can be incorporated into the prediction equation for %BF, have to account for several variables which cannot be measured if a quick and easy estimate of %BF is to be made. These variables will include hydration state for the Tanita method (limited conditions are stipulated for normal use) and, as demonstrated in this study, variations in size of the thoracic cavity. The thoracic cavity would provide a large degree of opposition to the flow of an electric current. Whilst in theory, conventional hand-to-leg BIA may be able to measure and predict for some variation in the composition of the trunk of the body because of the relative position of the electrodes, in reality this technology is not sufficiently sophisticated to detect and differentiate between every variable which affects the impedance to the electrical current. It is likely that this will apply even more to the bi-pedal Tanita BIA method, which must rely to a greater extent on the prediction equation, calculated from original calibration studies and body composition principles, together with data incorporated for each subject.

The T305 model is designed for clinical and/or health club use, so it can be assumed that some educated advice for interpreting %BF estimates may be given to users. The T511, however is designed for the domestic market and one of its selling points is that estimates of %BF can be recorded and recalled. The ethical concern here is that without appropriate guidance, those with a great concern about their body fat, particularly adolescent girls and slimmers, may have

their anxiety compounded by the relatively high %BF values given, and by the ease with which these estimations can be made and recalled.

4.8 CONCLUSION

The results of this study show that the Tanita TBF 305 and TBF 511 methods of estimating %BF do not give valid estimates when compared to densitometry. They may, however, be appropriate for use in large studies for relative estimates of %BF. There is particular concern about either method being used without qualified guidance to interpret results.

This study has also identified several other areas where further work would be of use. These includes the measurement of residual volume in older adults and intra-subject studies comparing body fat levels and hydration states in a range of predictive methods. Ultimately, a criterion method for estimating %BF is needed that has greater validity than D. With reference to the Tanita method of estimating %BF, it is important that the method is refined to be able to reflect the range of values which occur in the general population. Further studies should also be conducted on the T305 model in relation to the modes available for estimating %BF in children and in athletes.

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APPENDIX A

EXTENDED REVIEW OF LITERATURE

This considers the literature concerned with body composition studies, to provide background information for this research. The BIA method of estimating %BF is explained in more detail, with reference to studies which focus on this method.
Discussion on the effect of variations in RV is presented.

1.0 INTRODUCTION

This extended literature review aims to give a broad introduction to the subject of body composition, followed by a description of the range and application of methods of estimating %BF. This discussion will concentrate on the aspects of these methods which relate to the validity of their estimates, and to examples of populations where either the limitations or advantages of the methods are shown.

BIA as a method of estimating %BF will be considered in more detail after the general review This is to enable the studies involving BIA to be appreciated in relation to other methods. The BIA method which is the focus of this study has limited material published about it, and most appears to have been sponsored by the manufacturer, so there will be concerns about its objectivity. However, discussion of the wider issues relating to the measurement of body fat will suggest areas for further work in relation to this particular method.

2.0 THE RATIONALE FOR BODY COMPOSITION STUDIES

Body composition studies form part of Kinanthropometry: the study of relationships between structure and function in the body (Eston & Reilly, 1996, p.1). Understanding about the relative proportions and where possible, absolute amounts of the various components of body tissue can be of use in a variety of situations. For example, with the increased average age of human populations it is helpful to explore changes in proportion and composition of body tissues during the ageing process (Goodman-Gruen & Barrett-Connor, 1996). Competitive and recreational athletes and their trainers are aware of the links between performance and body composition, particularly in relation to %BF (Pacy, Quevedo, Gibson,

Cox, Koutedakis and Milllward, 1995). This interest, however, may not always be advantageous to the athlete, particularly in the case of young female athletes, for whom undue concern about %BF can lead to the development of eating disorders and thus the associated problems of bone loss and amenorrhoea (Barr, McCargar & Crawford, 1994; Bale,1994). Assessing the body composition of children is difficult: because of their continual growth the density and proportions of their body tissues will be in a dynamic state, and thus difficult to predict (Goran, Driscoll, Johnson, Nagy and Hunter, 1996). Advances in the technology for body composition studies is of interest to clinicians working with diseases and metabolic conditions which result in a change in hydration levels, e.g., kidney failure, coronary heart disease and metabolic disorders such as diabetes. Individuals with anorexia nervosa can now be monitored during illness and recovery to establish improvements in stores of both subcutaneous and visceral fat (Zamboni, Armellini, Turcaato, Todisco, Gallagher, Grave, Heymsfield and Bosello, 1997), although the CT scanning to effect this does have some disadvantages, not least of which are cost and availability. Workers in occupational health can also be assisted by the findings of body composition studies, for example, on the effect of the working environment on health and productivity.

3.0 DEVELOPMENT OF BODY COMPOSITION METHODS

Heyward (1996) reports that sum of skinfold measurements have been used as a guide to the amount of fat in an individual since the early part of the twentieth century. Like all methods of assessing body composition, SS is an indirect method: it is still impossible to actually measure the amounts of various body

tissues *in vivo*. All "measurements" of body composition are actually indirect estimates. The original studies which developed prediction equations for %BF were based on chemical analysis of only three white male cadavers (Brozek, Grande, Anderson & Keys, 1963). This work established the accepted relative densities of the fat and the fat-free body components, generally described as the "two compartments" in the "whole body" model for composition assessment. It is assumed that the fat and the fat-free compartments have steady densities (0.91 and 1.10 g/cm^2) respectively, both within and between individuals. Moreover, it is also assumed that the relative proportions of each compartment are constant and that an individual will only vary compared to the "reference" body in the amount of body fat. It can be seen that there are many opportunities for error if body composition estimates are based on these assumptions. Indeed, it is rather surprising that statistical agreement between methods and repeat estimates can be achieved at all. Despite these limitations, the 2-component model of the body, and its associated assumptions, are still used as the basis for many body composition assessment techniques. This includes D, the method traditionally accepted as the criterion or "gold standard" against which newer methods, such as BIA, are validated.

Several groups within a population are likely to have different densities of FFM than the "reference" body. These include athletes at one extreme and the frail but obese elderly at the other. The consequence of this is to under or over estimate %BF because the assumptions on which the two component model is based. Similarly, those with apparently higher densities, e.g., those with large RV, will be estimated to have a higher body density, and therefore a lower %BF than might be estimated using other methods.

SS has traditionally been used in field settings because it is cost effective and simple to conduct, although high variations between even well-trained technicians are reported. To estimate %BF from SS, a "proliferation" of prediction equations have been developed (Clarys et al, 1987) to calculate body density from anthropometric data. These equations are generated from regression analysis of various skinfold sums combined with anthropometric data from the population investigated. The wide variety of deposition patterns in subcutaneous fat explains why these predictive equations are very "population specific". "Generalised" equations, paradoxically, are only useful for the specific populations they were developed from (Sinning, Dolny, Little, Cunningham, Racaniello, Siconolfi & Scholes, 1985). However, "multicomponent models", such as those of Durnin & Womersley (1974), Jackson and Pollack (1976,1978 and 1980) and Lean, Han and Deurenberg, (1996) incorporate logarithmic transformations of the SS, together with "varying constants" according to age and/or other variables (refer to predictive body density equation from SS for this study in Appendix D). These equations give better agreement with D for estimating %BF for wider population, although statistically different mean values are reported.

4.0 NEWER METHODS OF ESTIMATING BODY COMPOSITION

Advances in technology have enabled other scientific principles to be used in estimating body composition. These newer methods include NIR, DXA, Total Body Water, CT and MRI scanning and BIA. NIR was assessed by Nielson, et al, (1992) to give %BF estimates within 5% of D. Total Body Water (TBW), measured by deuterium labelling (reviewed by Buskirk, 1986) or by recording the

level of naturally occurring potassium isotope, K^{40} , Myhre & Kessler (1966) reported good correlations between TBW and D. however, these older studies demonstrate the problems with the practical significance of correlation coefficients referred to earlier in this study.

The newer methods still have the inherent limitations of their traditional counterparts in that they all give indirect, estimated values of %BF. In addition, the more sophisticated, and potentially more detailed methods, also have the possibility of associated health risk. This is of particular concern with CT and MRI scanning (usually restricted to investigating body composition in specific clinical conditions) and DXA, which is suggested by some workers as a replacement for D as a criterion method. It is particularly useful in studies with children, who are unsuited to D, but many clinicians would disagree with Rissanen et al, (1994) who state that the radiation dose involved, equivalent to a single chest X-ray, is of "negligible" risk. However, with a reported error of $\approx$ 1.5%BF (Wellens et al, 1994), if cost and facilities are not limiting factors, it likely to be of interest as a replacement for less reliable methods such as SS, and possibly as an alternative "criterion". Several studies of %BF estimations have incorporated DXA in their validations (Rissanen et al, 1997; Webber et al, 1994; Wellens et al;1994).

5.0 BIOELECTRICAL IMPEDANCE ANALYSIS

BIA has been available for estimating %BF since the early 1960s (Heyward, 1996, p44). It works on the principle that if a small electric current is passed through the body between electrodes, that the drop in voltage across the electrodes will be in proportion to the TBW in the part of the body through which the current flowed.

This measurement of impedance (units: ohms Ω), or opposition to the flow of current, can then be used to estimate the non-water (and therefore fat-containing) component.

$$\text{Impedance } (\Omega) \rightarrow \text{TBW} \rightarrow \text{FFM} \rightarrow \%\text{BF}$$

Most BIA equipment uses single frequency current (usually 50Hz) but if variable frequency is used, the different characteristics of tissue within the TBW component of the body can be assessed, e.g., the relative proportions of inter- and intra-cellular water. This has obvious advantages for more sophisticated body composition investigations, although running multi-frequency BIA analysis tends to be time-consuming.

BIA predicts the %BF in the whole body on the basis that the body is shaped like a cylinder. A clearer assumption is illustrated in Figure 10 in the Discussion where the body is shown to be made up of linked cylindrical segments, which behave in series and with different resistances according to length and cross-sectional area. Impedance (which is mathematically computed as 1÷resistance, i.e., the reciprocal of resistance) will therefore vary according to the body segments sampled. Organ, Bradham, Gore and Lozier (1994) reported a new design for BIA %BF estimations which used additional electrodes to overcome this problem. This was described as "ipsalateral and contralateral impedance testing" and appeared to be a similar method to BS but with the addition of electrodes so that both the left and the right hand side of the body together with the body trunk could be assessed in turn. The obvious disadvantage of this method is the complexity of use. Once again, however, results in relation to other methods of estimating %BF were reported in terms of 'r'.

Research into the uses of BIA technology is of continuing interest. A web site exists at the University of Queensland, providing good quality technical information and the opportunity to exchange ideas and knowledge (http://www.biosci.uq.edu.au/BIA/BIA.html).

BIA equipment to estimate %BF has become very popular amongst "health conscious" populations such as those who frequent health clubs. It may be assumed from manufacturer's promotional material that the computerised technology has valuable (literally) revenue potential for clubs and other fitness related service providers. The validity of the estimates must however, be considered. Validation studies on BS and similar BIA equipment which quantify %BF differences have reported errors from 2.8%BF (Lukaski, Bolonchuk, Siders and Hall, 1990) to 0.76% (Jackson, Pollack,Graves and Mahar, 1988). These are somewhat lower than from the results reported here, but the nature of the samples were different, as was the BIA equipment used. This reflects a difficulty with the BIA method: prediction equations are manufacturer specific, and not available for inspection, so a researcher has to develop regression equations from data to establish what the significant variables in any one BIA method. This also makes comparisons between BIA methods increasingly complex: a validation study does not validate BIA but rather the piece of equipment that uses that technology.

5.1 TANITA BIA METHOD

The Tanita scales estimate %BF using the same technology as BS. However, because the flow of the electric current will go by the shortest possible route from foot to foot, there needs to be a factor in the prediction equation for the estimates

to compensate for the lack of measurement of impedance through the trunk of the user. It is assumed that the manufacturer's equation is intended to allow for this with addition of height and weight to the equation, together with age and sex of the subject. However, the work conducted here suggests that the amount of compensation that has been made for the error inherent in bi-pedal BIA %BF estimates is, so far, unsuccessful.

It is known that the major source of error in BIA methods in estimating %BF is in the placement of electrodes (Dunbar, Melahrinides, Michielli and Kalinski, 1994). Since the 4 electrodes in the T305 and T511 are "placed" by the subject when they stand on the scales, there could be a considerable amount of error in estimates because of incorrect standing position. This is of particular concern with T511, where the electrode pads were very small and the scales rather unstable. This could be explored in T305 with a repeated measures study, recording different standing positions for the same subject and comparing impedance measurements .

Another concern regarding the validity of the Tanita %BF estimates relates to the specification for hydration levels before taking a measurement. Although general guidance is given with T511, (users are advised to use the scales 2 hours after eating and preferably before taking exercise) there is a likelihood that lay users will not appreciate the effects of different hydration levels on estimates of %BF. This is particularly true for women, whose hydration levels vary considerably throughout the menstrual cycle and during pregnancy (Hopkinson, Butte, Ellis, Wong, Puyau & O'Brian Smith, 1977). It is possible that

the proportionate effect of one of the components of impedance, reactance, χ_c could be increased, which would reflect the electrical capacitance (i.e.water content) of the cell membranes and thus reflect to some extent, the hydration state of the user. Chumlea and Baumgartner (1990) noted the relationship between reactance and body hydration levels and stated that reactance was frequently ignored in the design of BIA equipment to estimate body composition. It appears, surprisingly, from the detailed report written by Nunez et al (1994) that the Tanita scales' recording of reactance is limited, so if this component can be given more consideration in future models, perhaps estimation could be improved.

6.0 STATISTICAL ANALYSIS OF COMPARABLE STUDIES

It has already been mentioned that many of the validation and comparative studies which have investigated methods for estimating %BF have used inappropriate statistical analysis, because they report a Pearson Product Moment Correlation, 'r'. It is hoped that future studies will be more thorough in their design, as advocated earlier. It is also apparent that there is the opportunity for research into different statistical methods for repeated measures research design. This is, however, an area outside the scope of this study.

6.1 EXTENSION OF THE BLAND & ALTMAN METHOD

Discussion of the statistical design used in this study raised two issues which need to be considered when the Bland & Altman method is used in validation studies. The first is its usefulness where a large bias exists between the tests being compared and/or where the 95% limits of agreement represent a wide range of values. The second issue is how to determine the significance of the plotted

results, other than by observation. To consider these matters further it is helpful to examine how the method has been used by other researchers.

Bland & Altman's original papers used a comparison between 2 methods of estimating peak flow. The calculation of the bias between the two methods illustrated a situation which is ideally represented by this technique: a relatively small mean difference, indicating that the "new" method varied only slightly from the "old" (or "criterion" method, in the case of a validation study). The next step in the process is to look at the spread of paired data within ±2SD: the 95% L of A. This calculation describes the "precision" of the new method. This may show that although the bias between the new and the old method is small, the 95% L of A are very wide, giving unacceptable agreement between two new methods. Alternatively, the 95% L of A may indicate that even extreme values within these limits would be within an acceptable range and that the new method could be used in place of the old. In some situations, Bland & Altman recommend a log transformation of the data. This may be helpful if there appears to be a recognisable pattern in the scatter plot of the paired data as it can reduce the limits of agreement and display the pattern of scatter more clearly (Bland & Altman, 1986).

A brief review of some studies which have utilised the Bland & Altman method illustrate how this technique has been used. Most report results which have a relatively small bias (i.e., mean difference) between methods. Lucia, Fleck, Gotshall & Kearney's (1993) validation and reliability study of the Cosmed K2 instrument for portable measurement of oxygen consumption showed small standard deviations from the mean difference and minimal bias with few individual

values outside the 95% limits of agreement. A study by Broomhead, Wright, Kiff & Withington (1997), which investigated the accuracy of two BIA methods of measuring cardiac output in anaesthetised pigs, showed a similar pattern of findings: low bias, small range of values within 95% limits of agreement and few outliers. In addition, a "Gaussian" distribution of values was displayed i.e., bell shaped or normal: again, this is what the researcher would hope to find if the methods are to agree. To make the mean difference clearer, Wellens, Chumlea, Guo, Roche, Reo & Siervogel (1994) added a zero bias line to the Bland & Altman plots of their data comparing methods of estimating %BF by different methods. This did not change the graphs but made interpretation of the bias clearer to see. Gutin et al's study of body composition in children (1996) used Bland & Altman's technique to show that although the bias between methods of estimating %BF were small, the wide 95% L of A between all the pairs of methods made it inadvisable for them to be used interchangeably. World (1996) used Bland & Altman's technique in his study of BIA monitoring of cardiac output in humans. This author displayed the bias together with 1SD and 2SD the bias, i.e., 66% L of A and 95% L of A. The lower limit may have applications in studies where the upper limit gives too broad a range of paired results and if few paired values come above the 66% level. Theoretically, if there is a normal distribution of data, 66% of the paired results should come within this limit and so even if the value of the limits of agreement gives a reasonable range, the proportion of values outside it may still make the "new" method of measurement unacceptable. Lean, Han & Deurenberg (1996) in their study predicting body density from anthropometric measurements, plotted the 95% L of A line and bias from a comparison between

%BF estimated by a regression equation developed from each method with %BF estimated from D. However, the bias line was displayed as a sloped rather than a straight line across the graph because it was intended to indicate not only the level of the bias but also the gradient. Although the authors do not explain why they have introduced this variation into the method of displaying the data, demonstrating the slope of the bias does give further details about the pattern of paired values, e.g., the direction of the bias at extreme values of %BF.

From the preceding review it can be seen that the Bland & Altman method can be adapted for certain patterns of results to enhance interpretation. The range of graphical displays which can be generated with computer technology permits further permutations of the methodology to be explored. However, for those who favour a more traditional approach to statistical analysis in validation studies, this method is mainly enhanced by combining it with a reportable test of significance: the paired 't' test.

7.0 RESIDUAL VOLUME IN OLDER ADULTS

This study found that estimated RV increased with age. There were noticeable differences between estimated RV and calculated or predicted RV for both male and female subjects in all age categories: estimated RV was the highest in all cases. Estimated RV of women above of 45 years of age was significantly higher than for younger women (refer to Appendix C: Additional Results). These findings are supported in the literature relating to the appropriate methodology for D and also in work concerning the effect of ageing on the physiology of the respiratory system.

7.1 THE IMPORTANCE OF ESTIMATED RV IN DENSITOMETRY

A number of studies have examined the effects of quantifying RV in different ways. This is because the process of estimating RV is cumbersome and because older subjects may find it difficult or impossible to achieve, because of the effort involved to attain and hold maximum expiration (Latin & Ruhling, 1986). Other workers have investigated the suitability of using Total Lung Capacity (TLC) for D because it was more comfortable and so subjects were able to stay submerged for longer (15 - 20 seconds compared to 5 - 10 seconds at RV), thus enabling the weight scale for D to stabilise and a more accurate recording to be taken (Timson & Coffman, 1984). The effect on the calculation of body density by using TLC is relatively small; when extrapolated to a calculation of %BF, using TLC underestimates %BF by 0.5% for men and 0.9% for women (Weltman & Katch, 1981) because the larger TLC increases the body density and thus decreases the %BF. Significant differences in %BF are calculated if TLC and/or RV are calculated on land and then compared to RV and/or TLC measured with the subject submerged up to the neck in water. This is due to the compressive effect of the water pressure on the thoracic cavity (Lundvall & Thorland, 1987; Timson & Coffman, 1984; Gibbons, Jessup and Bunting, 1985; Withers & Hamdorf, 1989). The range of prediction equations for RV were reviewed by Mayhew & Piper (1982). Their study looked at the effect of different prediction equations for RV and compared to estimation of RV by helium dilution in a sample of young male athletes. Their results showed, as in this study, that all the prediction

equations underestimated RV, thus increasing body density and underestimating %BF (estimated %BF decreases as body density increases). From this work it can be concluded that

(a) RV is preferable to TLC for D, provided it can be performed;

(b) Lung capacities should be estimated with the subject immersed to the neck;

(c) Prediction equations for RV give significantly lower estimates of %BF than estimates of RV by helium or oxygen dilution.

There are two further variables that affect RV, other than age. These are the practice effect of making repeated estimates and biovariability within a subject over time.

7.2 LEARNING EFFECT OF ESTIMATING RV

Several authors have noticed that repeating the methodology to estimate RV demonstrates a "classic trial to trial learning curve" (Lundvall & Thorland, 1987). Whilst this usually implies that practice leads to "better" measurements, it must also be remembered that with Wilmore's technique there is also the possibility that RV estimates will change over time because of the effect of repeated rebreathing of oxygen. To examine this possibility, one female subject volunteered to have repeated estimates of RV made. This was to observe how many estimates could be made before the $\%0_2$ in the rebreathed volume altered. It was discovered that, with a subject used to the technique, eight estimates could be made before the proportion of O_2 began to increase, presumably due to the lung tissues becoming saturated with O_2. Therefore it was concluded that some practice is required to obtain accurate estimates and that up to 7 or 8 trials will not affect the accuracy of the final trial.

7.3 BIOVARIABILITY OF RV

Marks & Katch (1986) reviewed the biological and technological variability of RV in relation to %BF estimations, suggesting that biovariability may be the largest source of variability in results. If technical error is minimised, as intended in this and other studies, there will still be variations in estimates of RV if subjects are measured on different occasions and therefore of estimates of %BF. Although the sample size for this study was small (5 men and 5 women) results showed a within-subject variability in estimates of RV taken daily over 5 days, of which 72% could be attributed to biovariability, and which would be equivalent to BF variation of ±0.9%. Whilst this may be equivalent to approximately 0.32kg body weight, a similar variation might occur as a result of the averaging of two trial RV estimates within 100 ml (see procedure for D), since the average estimated fluctuation between and within days in RV was ±30 ml. It is noted that the oxygen dilution method of estimating RV is very reliable, although this was concluded as a result of using the Pearson Product Moment Correlation Coefficient in the test-retest circumstances of compared RV estimates in the study. It was further noted that variation in RV increased with estimated RV and that the effect on %BF was dependant upon the overall volume of the body because of the way in which body density is determined. It would appear that although biological variability does exist, its magnitude may be no more than the effect of averaging 2 trials of

estimating RV at the time of hydrostatic weighing. Further work could be done with a larger sample to examine this factor in more detail.

7.4 VARIATION OF RV WITH AGE

Increased RV with age is generally accepted in the literature relating to physiology and geriatric medicine. Seymour and Seymour (in Pathy, 1989, p 6) note that this is due to loss of elastic tissue. Similar decline occurs in VC, estimated at 24.4 ml /year in men and between 12.7 and 18.3 ml/year in women, with greater losses reported for those living in urban areas (Shepherd, 1978). Activity levels have a militating effect, with very fit elderly men having a VC of up to 20% higher than their sedentary peers (Shepard, 1993). Explanations for these changes included reduced elasticity of the lung muscles, the effects of environmental pollution and a gradual loss of cartilaginous and fibrous support in the lungs which makes forces expiration more difficult. This last explanation is important when considering the appropriateness of estimating RV for D in older subjects.

In relation to this study, it would appear that the increased RV noted in the older subjects is to be expected. However, these subjects were not "old" in the gerontological sense, and it would therefore be interesting to explore how RV increases amongst subjects who would generally be described as "middle-aged" i.e., from ages 45 -65. This would be particularly so in the case of females, where the most significant changes in RV were observed. It may be, as has already been suggested, that the menopause may have effects on lung tissue, in addition to the initial effect of ageing. Again, the importance of estimating rather than predicting RV is reinforced, as these variations, which will tend to be individual rather than

general, would not be identified by prediction equations, even if an age factor was incorporated.

APPENDIX B

ADDITIONAL METHODOLOGY

A detailed description of the research methodology is given, with particular reference to the techniques required to obtain accurate data and to important considerations for working with volunteer subjects from the general public.

1.0 INTRODUCTION

This Appendix enables the author to discuss in more detail both the procedural and human aspects of this study. The importance of subjects' "compliance" to obtain valid data has already been mentioned in the Discussion. This is dependant to a large extent upon the researcher spending sufficient time and effort to explain the procedures carefully and allowing enough time for the protocols to be conducted in a smooth and efficient manner. When subjects are volunteers from the general public, as was the case in this study, it is particularly important to spend time on explaining what is involved before the subject arrives for testing, and to ensure that they have been given sufficient information with regard to the location of the testing area, the time required for testing, particular conditions which need to be fulfilled, follow up procedures and so on. This is not only important to ensure that the researcher and subject do not waste time by the volunteer arriving insufficiently prepared but also to maintain and one hopes, improve, the image of the institution where the research takes place. These considerations should, of course, also apply to studies where subjects are recruited from the local student body.

The detailed description of the study methodology is described chronologically, starting with the recruitment of subjects and then examining the sequence of procedures observed during the testing process.

2.0 RECRUITMENT OF SUBJECTS

Subjects were recruited by a variety of methods. A poster advertising the research study was displayed, with permission, in various locations at the research

institution, at the local leisure centre and the public library. However, it was found that recruitment was most successful when potential subjects were approached directly. Consequently, many of the subjects recruited were known to the researcher either through work or outside sporting activities. Initial expressions of interest were followed up by an informal interview or telephone conversation to explain what would be involved in the testing procedure. It was found that most subjects were concerned about the total submersion required for D, despite the researcher presenting the description of what would be involved in a reassuring manner. Some individuals decided not to take part in the study because they were unwilling to put their heads under water. These included several members of a local rowing club and others who were regular swimmers. The fear that many people have of submerging underwater, particularly when they are also required to achieve total expiration, should not be underestimated. This may be a significant factor in the acceptability of D and may limit balanced recruitment to studies using this procedure, particularly for older subjects for whom water based activities are unfamiliar. The researcher was also keen to establish that none of the subjects had problems with balance, mobility or stiffness, since this would have made entry into the hydrostatic weighing tank difficult (see Figure 4). Although D is regarded as having negligible health risk as a procedure, it was thought wise to check that subjects did not suffer from any respiratory problems, and to advise them not to participate if they had a cold at the time of their appointment. Following these discussions and an appointment for testing being made, the subjects were sent a letter confirming the details of the procedures, a map for locating the test site and a copy of the document for Informed Consent (see Appendix D). On the day of

their appointment, subjects who were unfamiliar with the research institution were met by the researcher and escorted to the test location.

3.0 PREPARATION OF THE TEST AREA AND EQUIPMENT

The test area was located in a room adjacent to a fitness suite. Access to showers and toilet facilities were on the other side of the fitness suite, hence the advice to subjects to bring a bath robe. Due to limitations on equipment the balanced beam scales and the floor mounted stadiometer were in an adjoining building, so subjects also had to leave the test area for weight and height measurements to be taken. Ideally, for reasons of efficiency and privacy, all these facilities would be located in the testing area. Although the test area contained equipment other than that required for the study, some effort was made to make it as clean and tidy as possible, since it was felt that this would reassure to the subjects, many of whom were unfamiliar with the "exercise testing" environment. The hydrostatic weighing tank, which was of obvious concern to many subjects, occupied a central position. The load cell apparatus for underwater weighing was located over the tank by means of a metal frame, which as one subject commented, had a unfortunate resemblance to a gallows. In order to "lighten" its appearance, a simple poster was attached to the side of the tank opposite the entrance to the room (see Figure 4). It was hoped that this helped to reduced the subjects' anxiety.

Although the test procedures took between 75 and 90 minutes for each subject, an additional hour was needed at the beginning of each day's testing to allow time for the gas analysing equipment to be calibrated. Whilst this could have been done during the procedures, it would have meant that the researcher would

have to interrupt testing to collect samples of calibration gases, possibly loosing concentration and also leaving the subject alone in an unfamiliar environment. It was therefore decided that the additional time required was important for the success of the study. In other circumstances where technical assistance is available, several of the preparation procedures could be done by others. However, in the situation described here, this would have limited the researcher's control over the routine and the learning opportunities it afforded. The routine for conducting a test session will now be described.

The test equipment that required advance preparation were the gas analysers (for the estimation of RV) and the hydrostatic weighing tank. Two analysers, one for oxygen (Servomax Analyser 570A, Servomax Ltd., Crowborough, U.K.) and one for carbon dioxide (Servomax IR Gas Analyser PA404) were required. The analysers were connected so that each sample of gas used to calibrate or to be analysed would pumped through both machines. The analysers were switched on for 60 minutes before being calibrated. First, a sample of pure nitrogen, collected in a gas sampling bag which had been flushed out 3 times with nitrogen, was used to calibrate at zero. Then a sample of a calibration gas (Certified Gas Mixture, BOC Ltd., Guildford, U.K.), composed of 20.09% 0_2, 5.0% CO_2, and the balance of N, collected as described previously, was used to calibrate each analyser. A 250l Douglas Bag, used to hold pure O_2, for later use in the estimation of RV, was flushed out three times with pure O_2 and filled from a O_2 cylinder which was stored appropriately in the testing area. The purity of the gas collected in the Douglas Bag was later checked before use with the gas analysers. Prior to the analysers being calibrated, the hydrostatic weighing tank was prepared.

This involved washing the tank out after its previous use, using a small quantity of proprietary bathroom cleanser. Particular attention needed to be given to the water level line which, because of the slightly roughened interior surface, tended to accumulate small amounts of debris. The tank was then rinsed and water of the correct temperature (approximately 36°C) used to fill the tank to a suitable level. With this particular type of tank it was important to know how long the filling process took, as there was no overflow. A proprietary brand of water sterilising tablets were added to the water; the quantity used being determined by the volume of water in the tank. It should also be noted that the seat which the subject sat on during the D process was not suspended from the load cell apparatus until the subject was ready to enter the tank, and was removed as soon as the procedure was complete, before the water was drained away. This was to prevent damage to the load cell.

Prior to the arrival of the subject, the other equipment required for testing and supplies of materials were checked: electrodes for BS, an adequate supply of paper in the T305 printer, marker stickers for SS, a recording sheet for the Vitalograph, medical gloves for handling the RV estimation mouthpieces, a bowl of sterilising solution and a numbered folder with the data recording sheets, Informed Consent form and Activity Questionnaire. The additional equipment for estimating RV was assembled as far as possible.

4.0 THE DATA COLLECTION PROCEDURE

On arrival, subjects were shown the test area. The test routine was explained, the Consent forms signed (one for the subject and a copy for the researcher) and it was

checked that the subject had met the conditions required for testing. Next the subject changed into swimwear, removed any jewellery, passed urine if possible, and had their height and weight recorded. Height was measured to the nearest 0.1cm with a floor standing stadiometer (Seca 2m stadiometer, Seca, Germany) and weight to the nearest 0.1kg with floor mounted balance beam scales (Seca 160kg/400lb scales, Seca, Germany). Care was taken to ensure that the subject stood correctly (head held in the Frankfort plane) when height was measured.

The first estimates of %BF were made with T305 and then T511 (see Figure 5). This was useful because measurements were simple to obtain and the use of the equipment enabled the researcher to clearly explain the purpose of the study. The subject's sex, age and height were keyed in to T305, with "standard" being selected as the activity level. Their weight, given by these scales, and %BF were recorded and the printer output retained. A discussion of the estimate was offered and it was found that the subjects were very interested in possible interpretations of their data. The T511 scales were used next: most subjects needed to hold the edge of a nearby bench to balance correctly on the metal foot pads. Sex and height were keyed in using the dial situated on the upper surface of the scales; again, weight and %BF were recorded.

The next estimate was made with the second BIA equipment: BS (see figure 6). The subject lay in a supine position on the floor, with limbs extended and relaxed for 5 minutes before readings were taken, during which time the electrodes were carefully placed on the right-hand wrist, hand, ankle and foot according to the manufacturer's instructions. Data giving the subject's sex, age, activity level ("medium" for all subjects) weight and height (using the

measurements taken before testing commenced) were entered, and the measurement taken and recorded. Subjects were advised to get up slowly from the floor, to minimise any sensation of giddiness (more likely than in younger subjects because of increased age and the effects of fasting for 4 hours prior to testing).

Estimates of body density from SS, and thus estimation of %BF, were calculated next, taking skinfold measurements from the biceps, triceps, suprailliac and subscapular sites on the right-hand side of the body. Harpenden callipers were used (Figure 6). The location of each site was measured and marked, following guidance from Lohman (1991). The suprailliac fold site on the midaxilliary line was chosen in preference to that above the hip bone on the anterior surface of the body. This is because it was easier to locate, giving greater accuracy of measurement and caused less intrusion to the subject. Three readings were taken at each site, with time allowed for the body tissue at the site to recover between measurements, and the mid value used for the sum. The researcher was able to attain identical measurements at most sites with the first 2 readings.

The SS measurements completed the first half of the testing process. The following work, which took between thirty and forty five minutes, involved estimating RV and weighing the subject underwater.

The first stage in RV estimation was the measurement of VC. This was done using a Vitalograph (Vitalograph Limited, Buckingham, U.K.), illustrated in Figure 7, with the subject standing and wearing a nose clip to minimise the risk of exhaling other than into the mouthpiece. A new disposable cardboard mouthpiece was used for each subject. Following the normal procedure, the subject inhaled maximally and exhaled into the mouthpiece: the pen recorder marking the exhaled

volume on the vertical axis of the chart. This process was repeated twice more but with the subject holding their forced breath to attain maximum expiration. The mean value of forced VC was recorded. 80% of this volume as O_2 was subsequently used to fill a rebreathing bag for the estimated RV process.

The simplified method of estimating RV described by Wilmore (1980) was used in this study. This involves measuring the proportions of CO_2 and O_2 in a 5l rebreathing bag, originally filled with pure O_2 (80% x VC in litres) which the subject re-breathes during a specific number of full inhalations and exhalations. If the facilities are available, this is most accurately done with the subject totally submerged but at this site, the procedure was conducted with the subject immersed to the neck in water, in the hydrostatic weighing tank.

At this stage in the testing, the seat was introduced into the hydrostatic weighing tank and suspended from the load cell apparatus, firstly ensuring that no air was trapped in the metal casing of the seat. The load cell weight recording apparatus (Novatech M865 Loadmeter, Novatech, Hastings, U.K.) was switched on and tared by adjusting the reading to zero. The subject, having showered, was assisted into the tank and sat on the seat whilst the rebreathing equipment was prepared. This was a useful opportunity for the subject to become accustomed to the tank: the warm water certainly helped them to relax and they were encouraged to practise, in their own time, dipping their head under the surface of the water and exhaling. Putting this part of the procedure under the control of the subject appeared to give confidence. RV was estimated by the subject rebreathing the measured volume of O_2 in the bag. This was measured into the bag using a 3-way stopcock valve (2100 Series, Hans Rudolf Inc., Kansas City, U.S.) connected to

the Douglas Bag containing pure O_2 , a calibration syringe (3-litre Series 5530, Hans Rudolf Inc., Kansas City, U.S.) and the rebreathing bag (Figure 8). By marking the required volume on the syringe, the correct amount of O_2 could be extracted from the Douglas Bag and then, by altering the valve connections, transferred into the rebreathing bag, which had previously been flushed out with O_2 and emptied using the pump on the gas analysers. This process was somewhat cumbersome and time-consuming but was much easier than using a spirometer to measure out the gas volumes, as indicated in Wilmore's (1980) original description. Also, a calibration syringe is unlikely to leak, which is a common concern when using a traditional spirometer. Once prepared, the filled and sealed bag was introduced to the subject, with a sterilised solid mouthpiece in place, inserted by the researcher using medical gloves to prevent any possibility of infection. Wearing a nose clip the subject was instructed to practice taking full breaths in and out of the mouthpiece connected via the 3-way valve to room air. The subject then held out a maximal expiration whilst the valve was closed to the room air and opened to the rebreathing bag. The subject took 6 - 7 full breaths in and out, carefully counted aloud and timed (one breath every 2 seconds) by the researcher. Wilmore noted that this was particularly important to ensure adequate mixing of the lung gases and the rebreathed O_2 . On the last expiration the subject held their breath out until the valve to the rebreathing bag had been closed. The rebreathed gas was then analysed for % of expired CO_2 and O_2 , and RV estimated using the equation given earlier. Following measurement of RV from this data and the rebreathing bag being flushed out with O_2 , and the process was repeated until two estimates within 100ml were obtained. This usually occurred by the second or

third repetition; one subject had difficulty with the breathing procedure and had the process repeated five times. (As a precaution, a volunteer subject agreed to repeat ten estimations of RV using this method to investigate the consequence of repeated rebreathing, in case prolonged breathing of O_2 resulted in pulmonary disturbances and/or changes in estimated RV, due to the lung tissue becoming saturated. It was found that estimated RV values stabilised within five repetitions but began to alter after six or seven. Therefore if subjects had required up to four or five attempts before agreement was reached this was considered acceptable).

The final stage in the testing procedure was hydrostatic weighing. The subject had by this time become accustomed to the tank. Prior to submersion the water temperature was recorded, for correction of water density, and the air temperature noted. Wearing a nose clip if desired, the subject was then helped to learn how to submerge under the surface of the water whilst expiring. Some subjects found this relatively easy whilst others needed some time to become confident. It was found useful to instruct subjects not to breathe in too deeply and to start expiring as they lowered their head under the water. This probably helped because it overcame the natural reaction to hold the breath under water. Further practise enabled almost all the air to be expelled, so at this stage, the underwater weight was observed. Due to the construction and operation of this particular hydrostatic weighing tank, it was necessary for the researcher to stabilise the seat in the tank whilst the subject submerged. This was because any sudden movement disturbed the sensitive load meter and made it difficult to obtain a steady reading. Subjects soon learnt how to expire maximally, and after this asymptote was usually reached within 3 or 4 readings. Following 3 consecutive equal readings at

maximum expiration, the load cell was switched off and the subject assisted from the tank The researcher was aware that this stage was reached with some relief by most subjects, since the test process had been lengthy. The seat was disconnected from the load cell and removed from the tank, which was drained unless another testing procedure was to follow immediately.

The subject was encouraged to drink and eat a snack as soon as possible after the testing procedure was completed. It was also important that they kept warm.

The procedures described above were conducted as accurately as possible but it must be recognised that there were some limitations imposed by the range of equipment available. As previously mentioned, RV may be estimated using helium dilution techniques and by taking the measurements during total submersion, thus maximising pressure on the thoracic cavity to expel as much air as possible. This requires expensive equipment not available for this study. Tanks situated at a lower level and with a fixed seat or by using a seat in a hydrotherapy pool would be more comfortable for both subject and researcher. For work with older adults and/or those with obesity or mobility problems were to be tested, these facilities would be essential.

Figures 4 - 9 follow to illustrate the equipment and data collection used in this study.

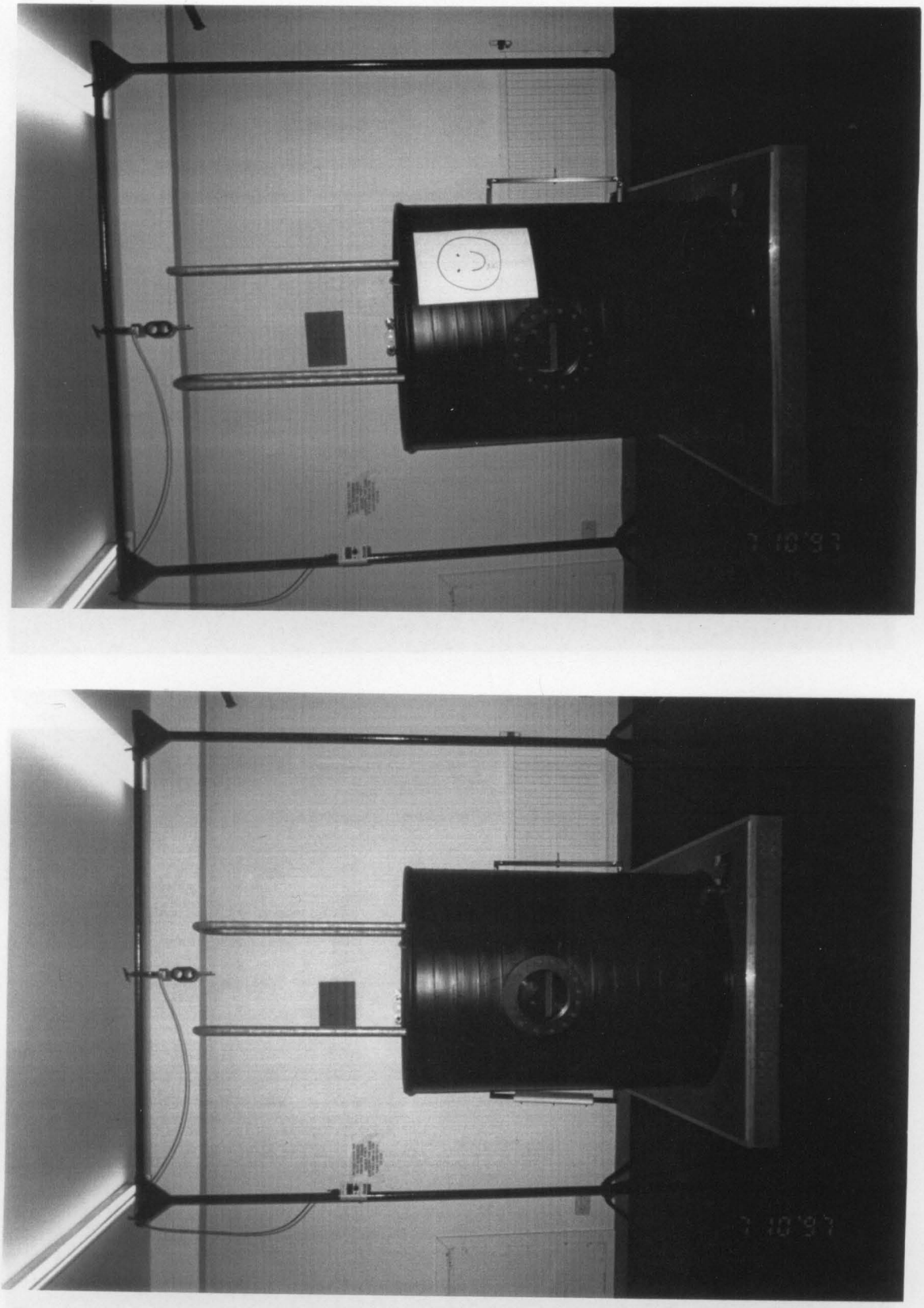


Figure 4: Hydrostatic weighing apparatus.
Right-hand photograph shows poster used during testing sessions.

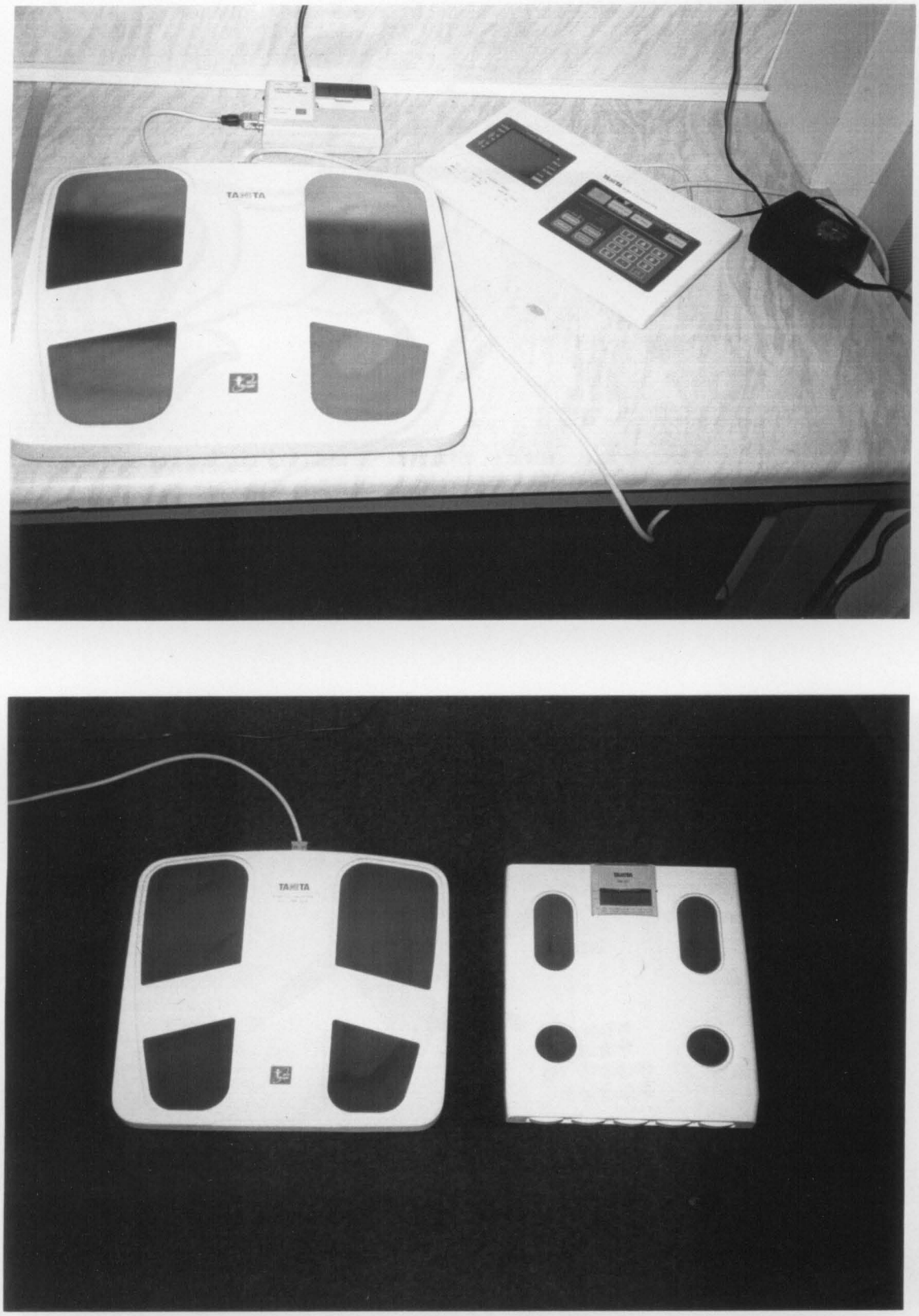
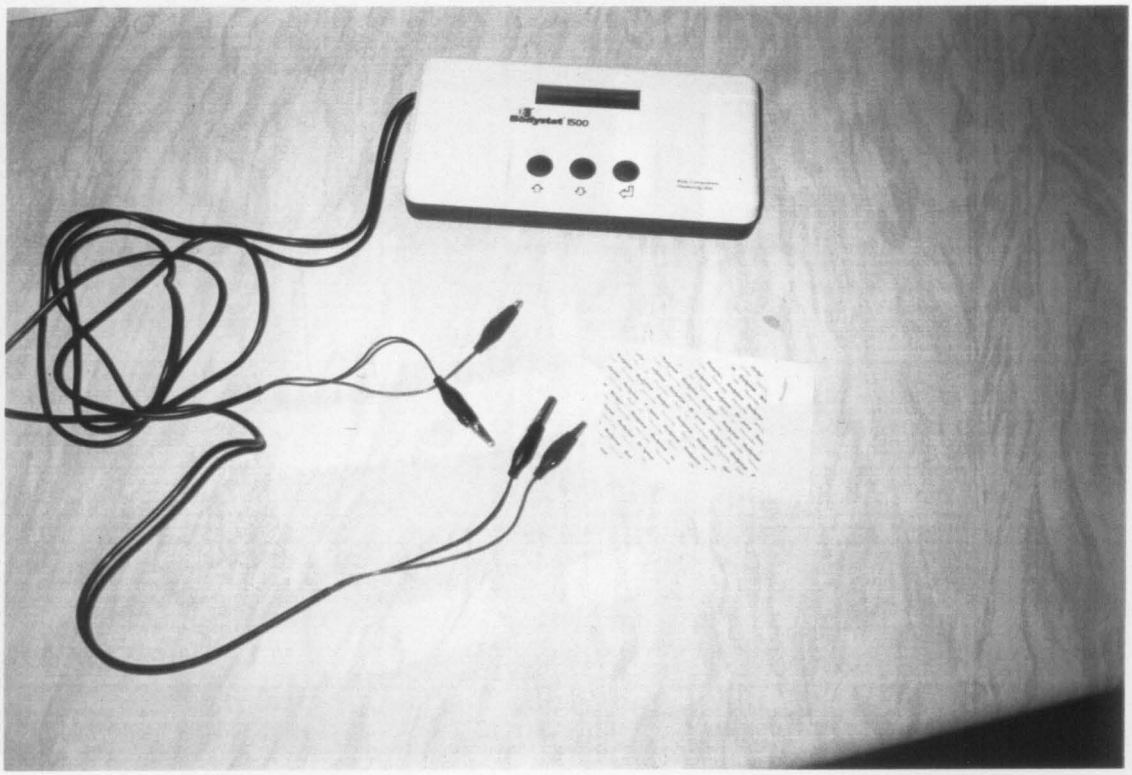


Figure 5: Tanita models TBF 305 (above) and TBF 511.
Note the relatively small size of the foot pad electrodes in TBF 511,
which could result in inaccurate impedance readings.



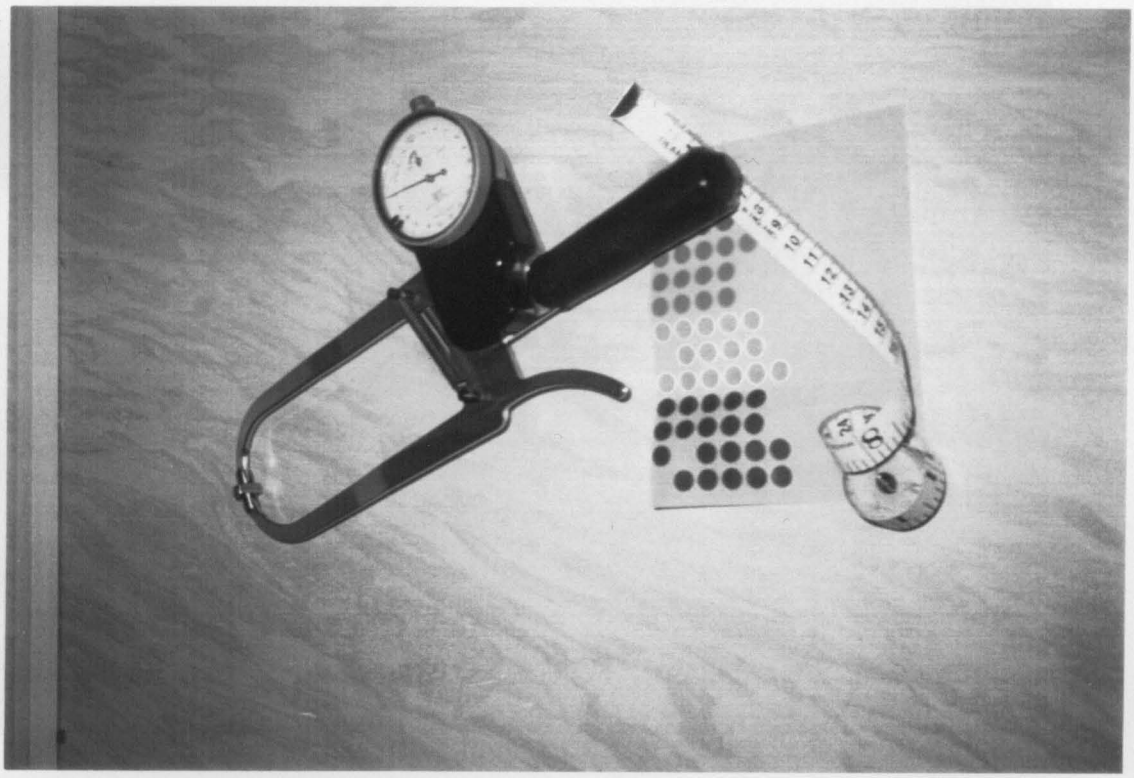
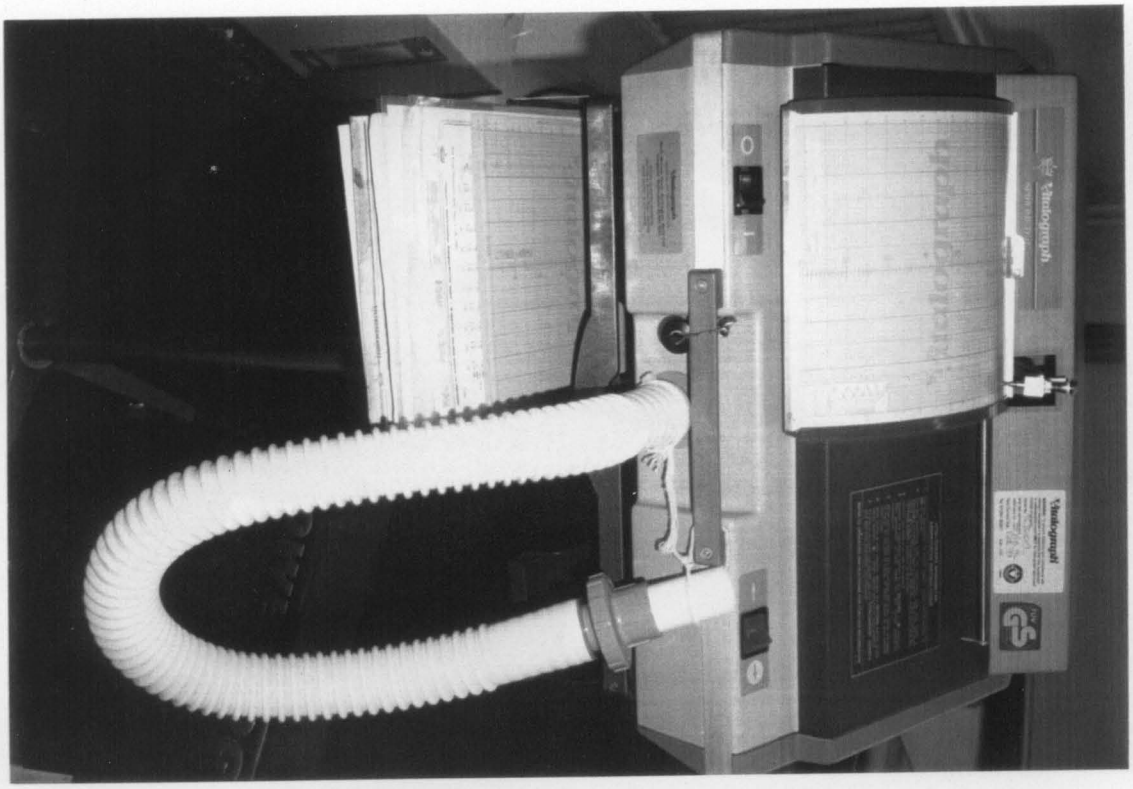


Figure 6: Bodystat 1500 (above) showing electrode pads.
Harpenden calipers (below) for SS, plus site marking equipment.



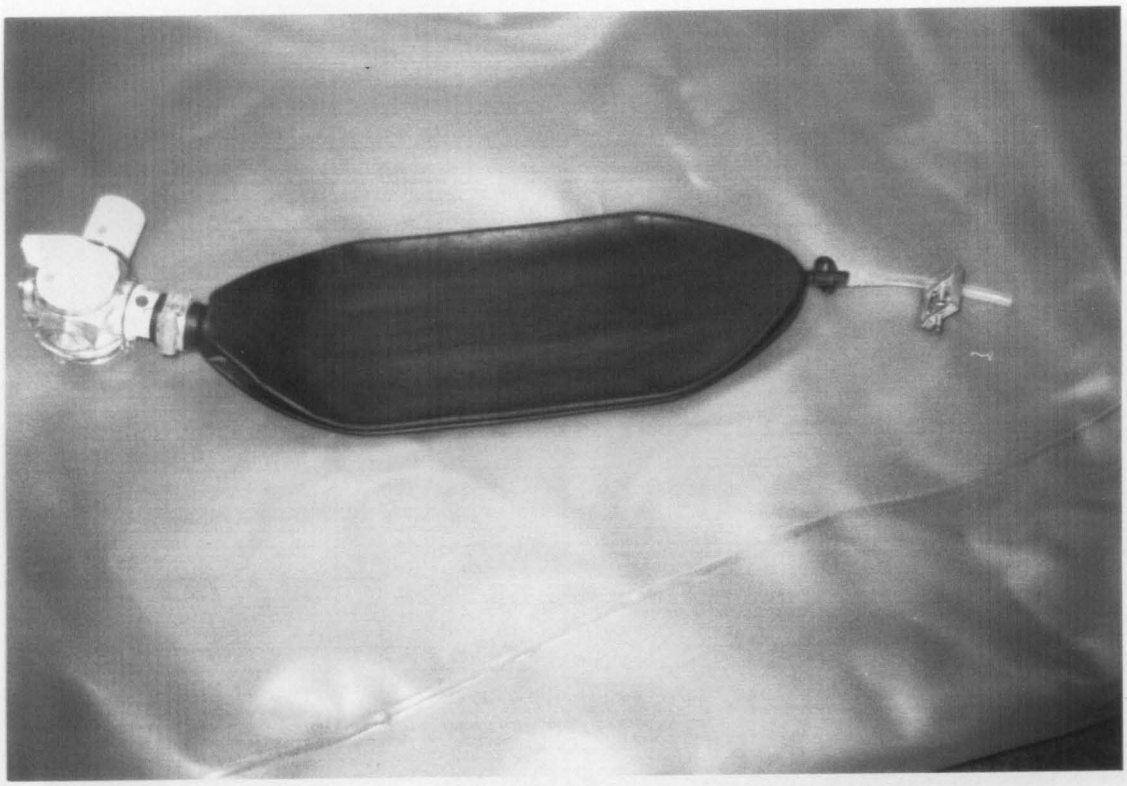
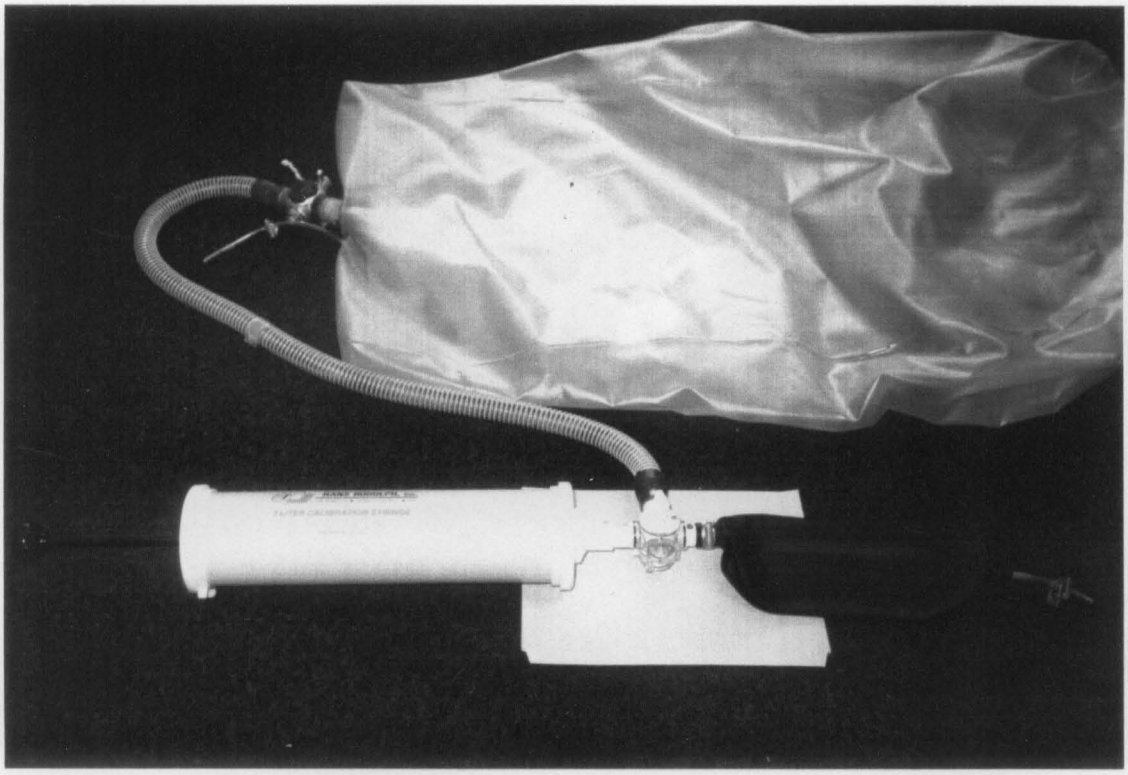


Figure 7: Estimation of RV: Vitalograph (above) and 5 litre rebreathing bag + valve.
Note small tube and clip at base of bag, connected to gas anayser pump for flushing out procedure.



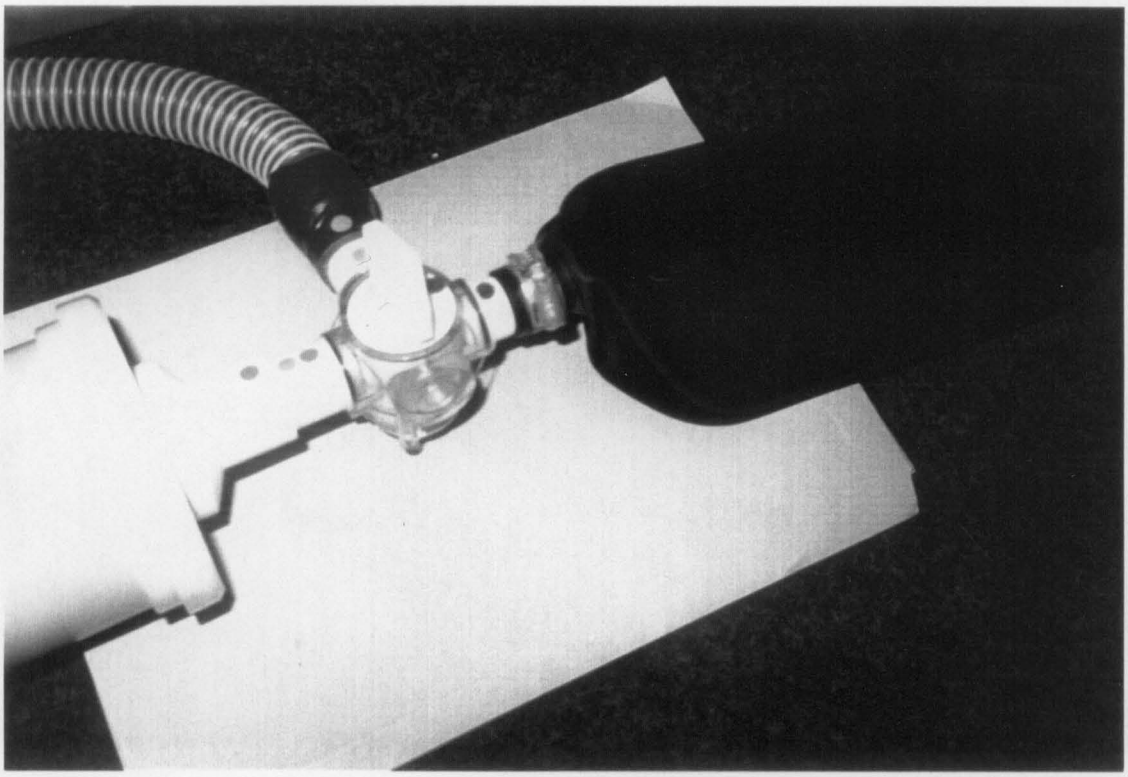


Figure 8: Equipment for estimating RV.
Lower photograph shows detail of 3-way valve connections.

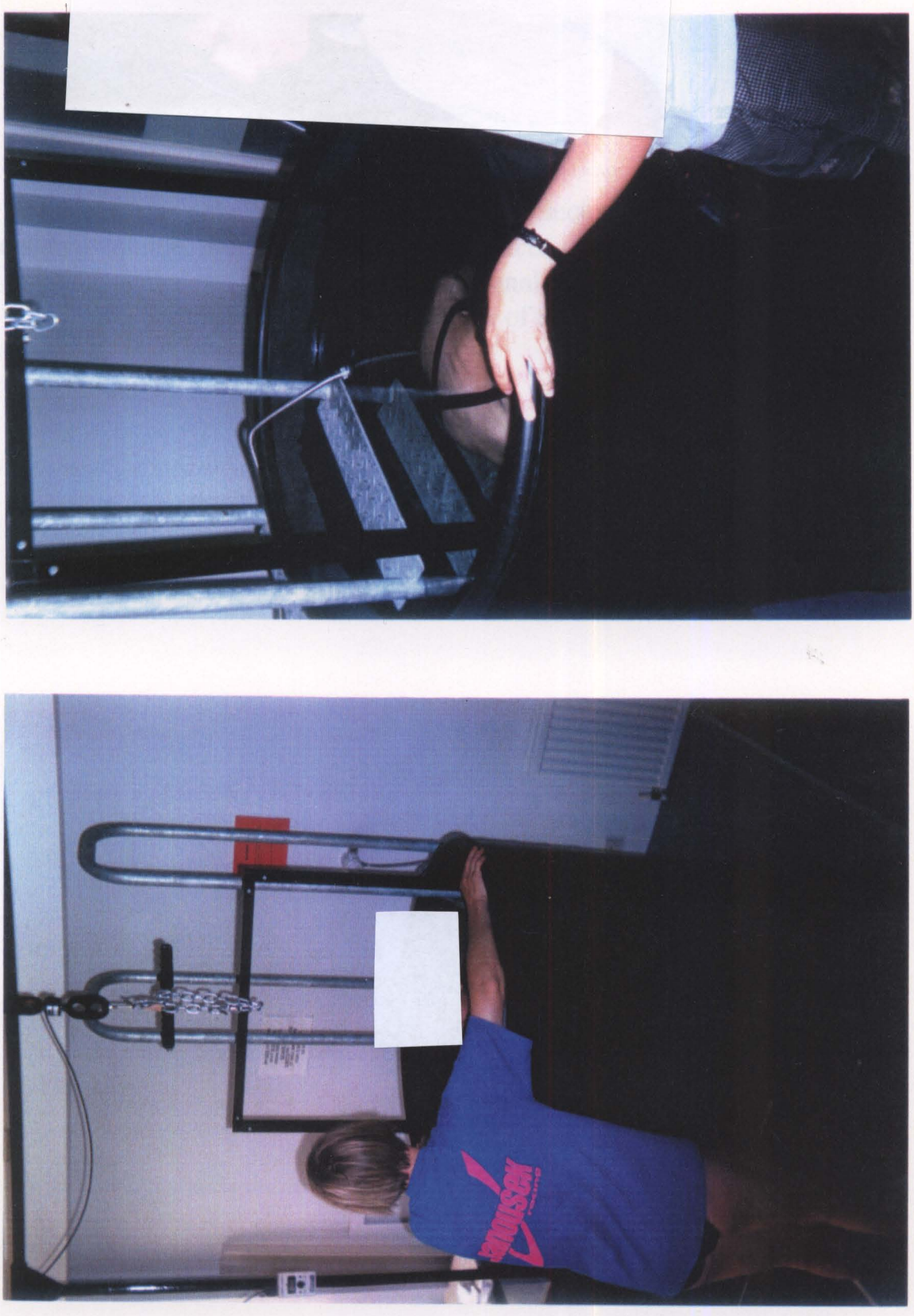


Figure 9: Hydrostatic weighing in progress.
Left-hand photograph shows seat being steadied prior to subject submerging.

APPENDIX C

ADDITIONAL RESULTS

This contains details of additional work conducted on quantifying residual volume, the raw data from all subjects, computer output from statistical analysis of the data and additional graphical displays of results referred to in the main body of the Dissertation.

1.0 QUANTIFYING RESIDUAL VOLUME

One of the most interesting findings of this study was in the results of estimating RV. When the research protocol was being designed, discussion took place as to whether RV should be estimated or calculated from 0.24 VC, since the latter method saves a considerable amount of time and reduces the stress of the D process on the subject. However, following investigation of the literature, it was agreed that calculation of RV could lead to significant error in the calculation of body density from D, and thus of estimated %BF. This decision was supported by the estimates of RV obtained in this study, which, when compared to values obtained by calculating RV from 0.24 x VC or by prediction from age and weight (Boren, 1963) gave significantly different estimates of %BF. These results have been reported elsewhere (Cotterell, Irving and Sykes, 1997). Figure 16 shows the effect of quantifying RV by different methods to estimates of %BF. The implication for the results of this study relate to comparable validation studies where D is used as a criterion method and to BIA methods where the effect of the shape of the body and its internal composition need to be accounted for in manufacturer's prediction equations for %BF.

In D, if RV is not estimated by oxygen dilution, or by the more sophisticated technique of helium dilution used in some studies (Withers & Bell, 1988), %BF estimates from D are likely to be higher and thus may give greater agreement with the other methods used here. It was found that RV in this sample increased significantly in women over the age of 45, and that if measurement is not possible, for this sample a calculation of 0.46 x VC gave closer agreement with estimated RV than the usual 0.24 x VC. It was considered that this phenomenon

may result from changes to the fluid retention of the tissues of the respiratory system which take place during the menopause. Other possible explanations include environmental influences

1.1 ESTIMATED, PREDICTED & CALCULATED RV

The methods used were as follows:

1. Estimateded by oxygen dilution (Wilmore, 1980): RVE.
2. Calculatedted as 0.24 x VC: RVC
3. Calculated as 0.46 x VC: RVC2
4. Predicted from height and weight (Latin and Ruhling, 1986): RVP.

Figure 10 gives the results of VC measurements for male and female subjects. Whilst VC did not significantly alter with age in male subjects, it did decline significantly ($p<0.05$) in female subjects.

RVE was initially compared to a calculated value for each subject, VC x 0.24 (Figures 11 and 12) to find if any similarities could be observed between this calculation and estimated RV. It was noted that RVE was always higher than RVC but did not appear to vary with age. In women, RVE was higher than RVC. However, RVE increased with age but RVC did not.

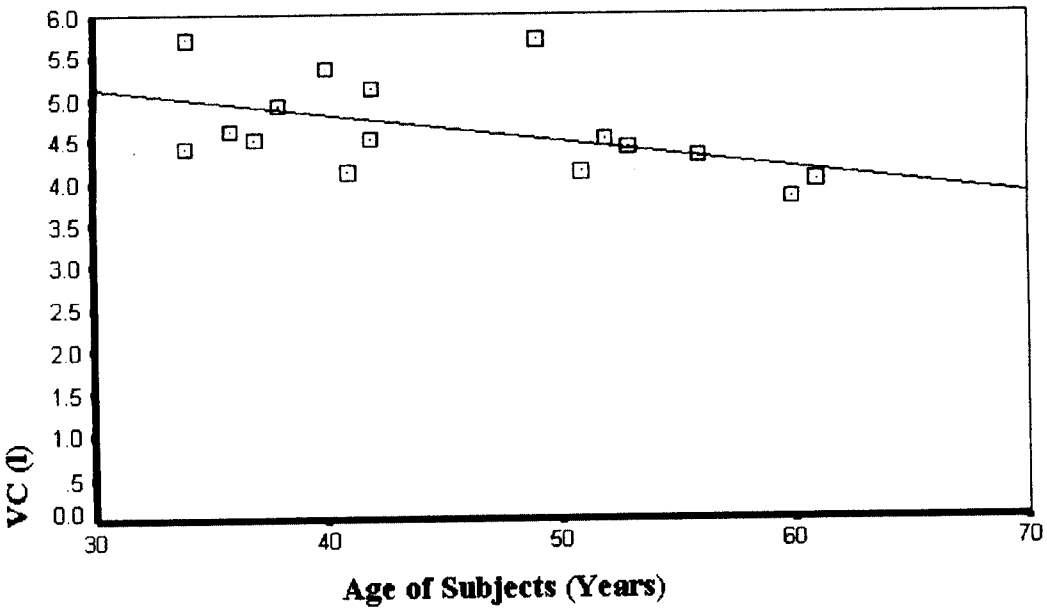
The differences in RV were particularly noticeable when values were broken down by age group: Figures 13 and 14. One-way analysis of variance combined with a Tukey HSD post-hoc test demonstrated a significant difference between the values for RVE in women over the age of 40 ($p<0.05$). As a further comparison, Figure 15 demonstrates the magnitude of difference between several methods of establishing RV for the subjects in this study, where RVE was used as the basis for

the calculation of body density in D. It was established that predicting RV from height and weight, or calculating using a constant of 0.46 x VC (rather than 0.24 x VC) gave a closer approximation to RVE.

Figure 16 shows the effect on calculations of estimated %BF of each method of calculating RV. The consequences were that if body fat had been estimated using RVC it would have overestimated by a total of 6.6 - 7.7% (an error of 31 - 41%) compared to using RVE by oxygen dilution.

The graphs which display the results of this aspect of the study appear below as figures 10 - 16.

VC Measured in Men



VC Measured in Women

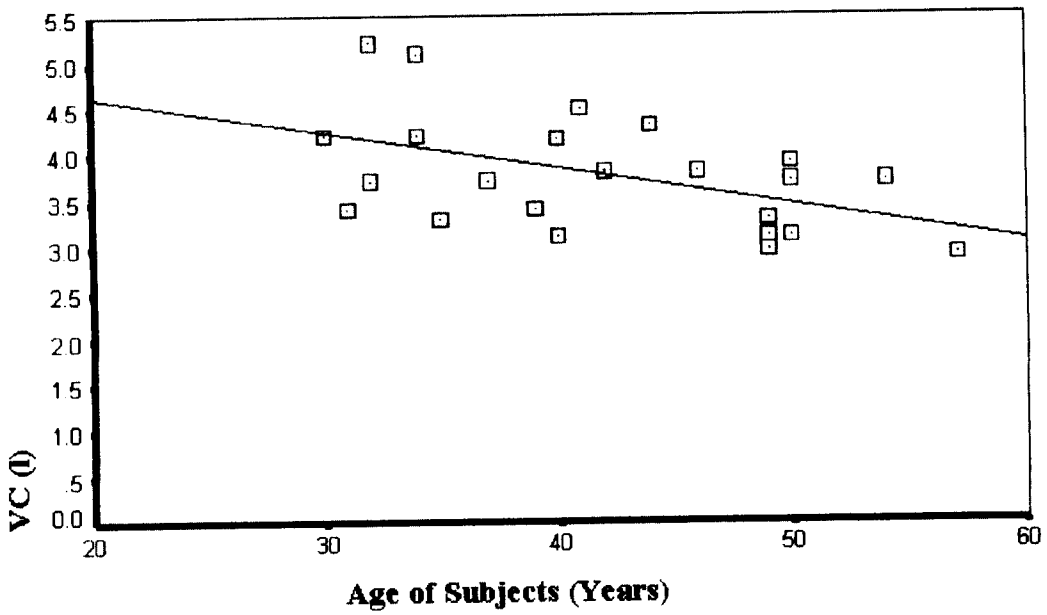


Figure 10

RV Calculated (RVC) and RV Estimated (RVE) in Men

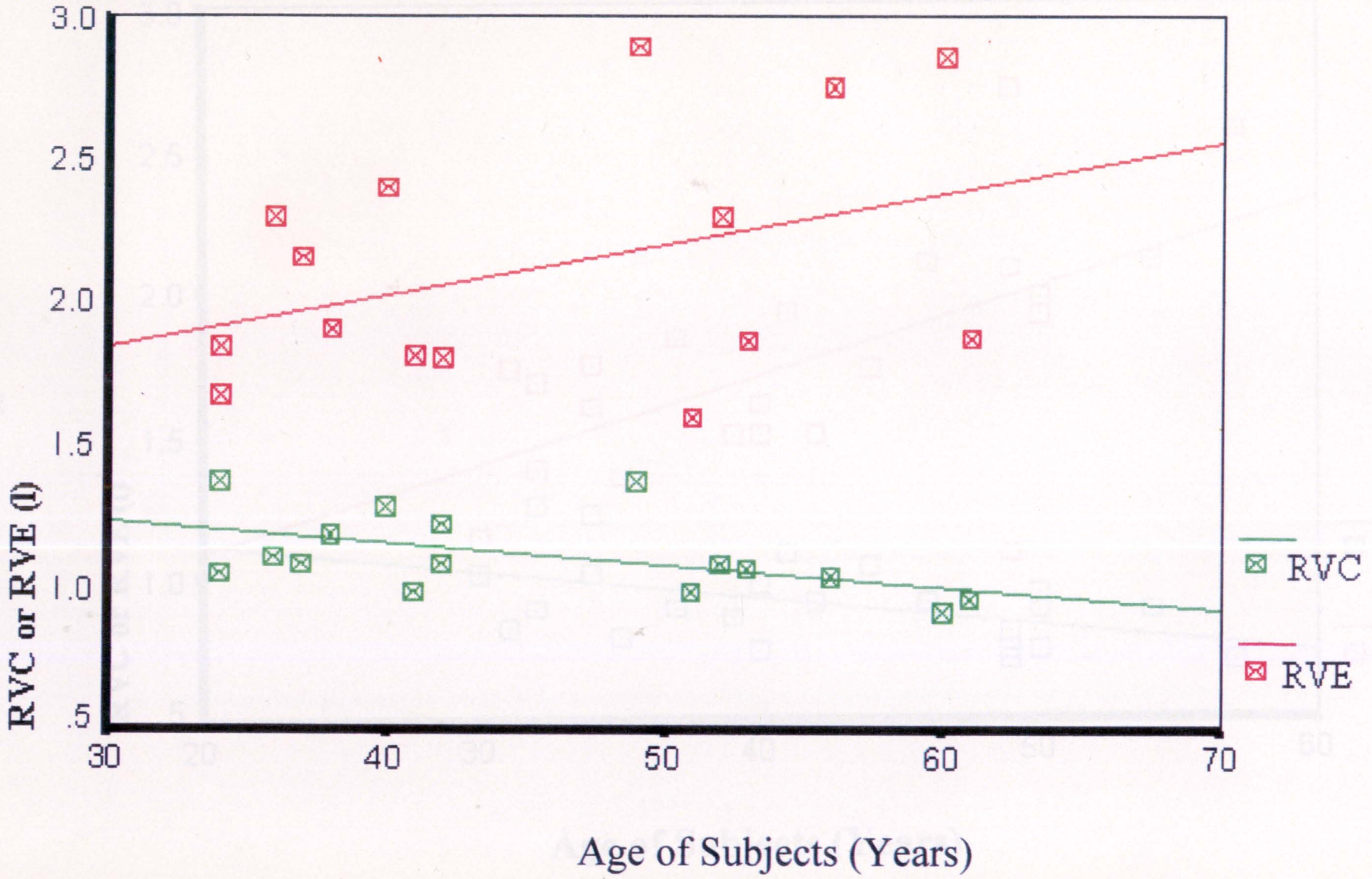
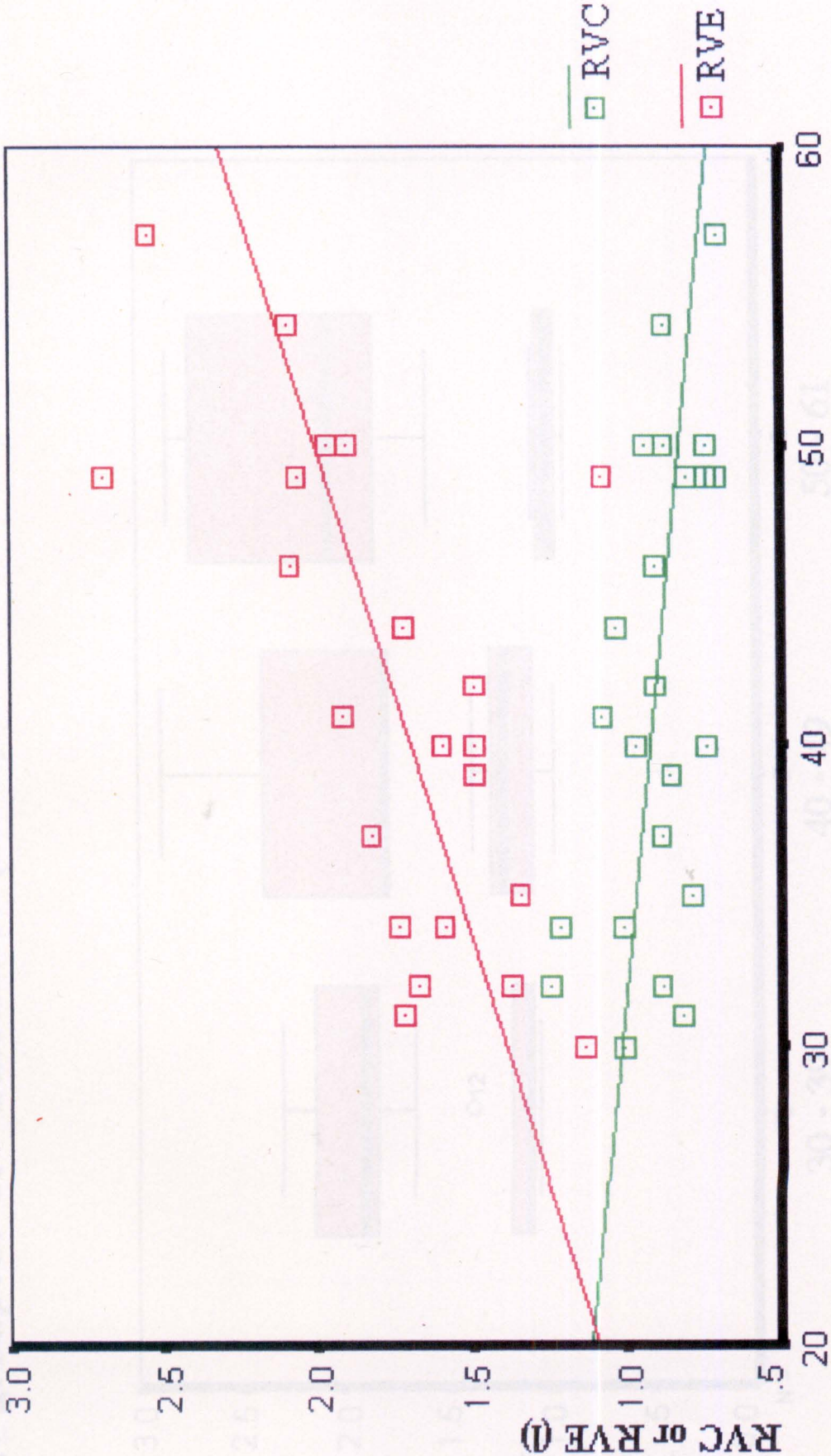


Figure 11

Figure 12


RV Calculated (RVC) and RV Estimated (RVE) in Women
RVC
RVE
RVC or RVE (l)
3.0
2.5
2.0
1.5
1.0
.5
20
30
40
50
60
Age of Subjects (Years)

Age-grouped: RV Calculated (RVC) and RV Estimated (RVE) in Men

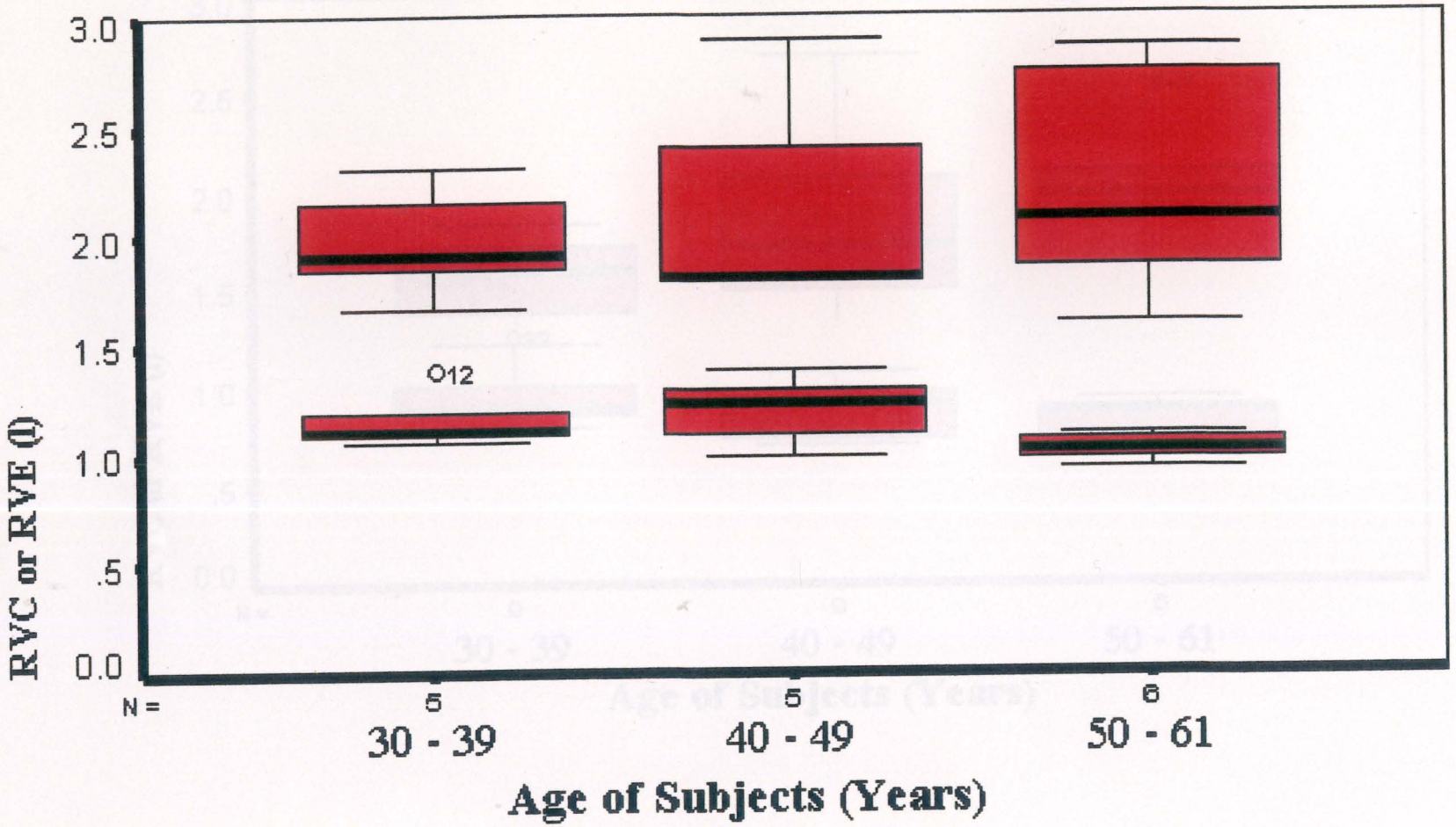


Figure 13

Age-grouped: RV Calculated (RVC) and RV Estimated (RVE) in Women

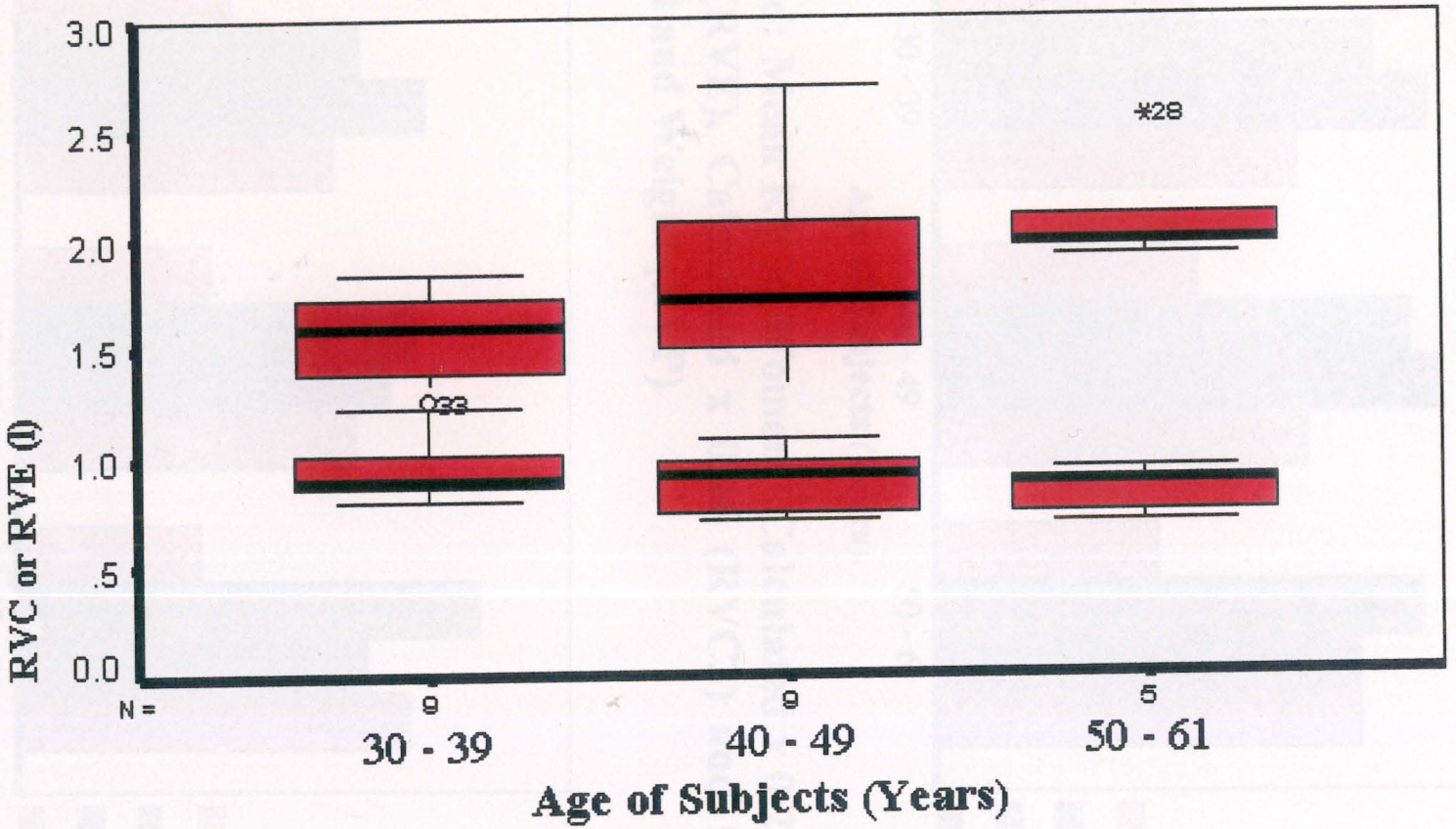
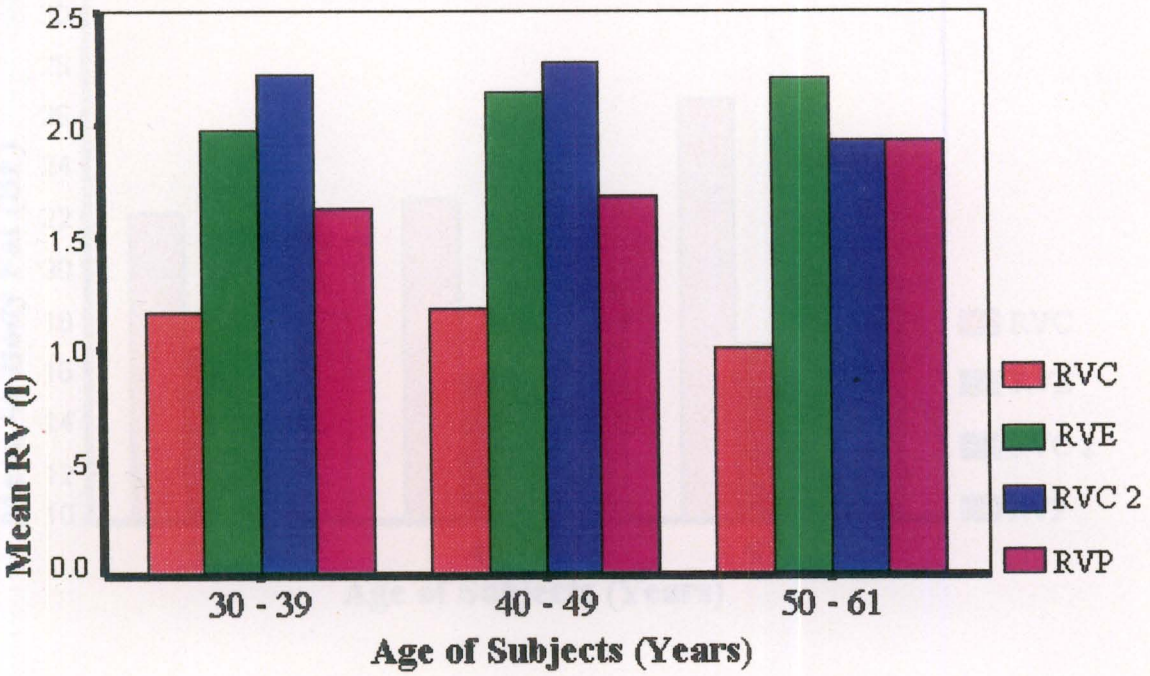


Figure 14

Age-grouped: Mean RV in Men. Calculated x 0.24 (RVC), Estimated (RVE), Calculated x 0.46 (RVC2) and Predicted from Height and Weight (RVP)



Age-grouped: Mean RV in Women. Calculated x 0.24 (RVC), Estimated (RVE), Calculated x 0.46 (RVC2) and Predicted from Height and Weight (RVP)

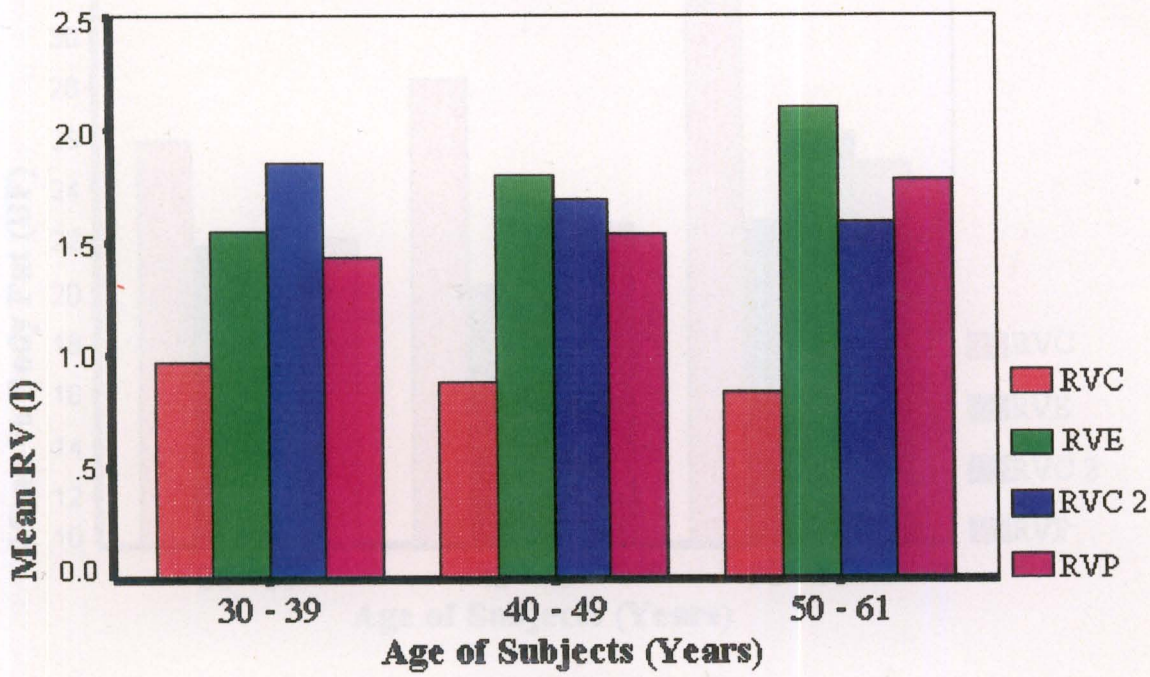
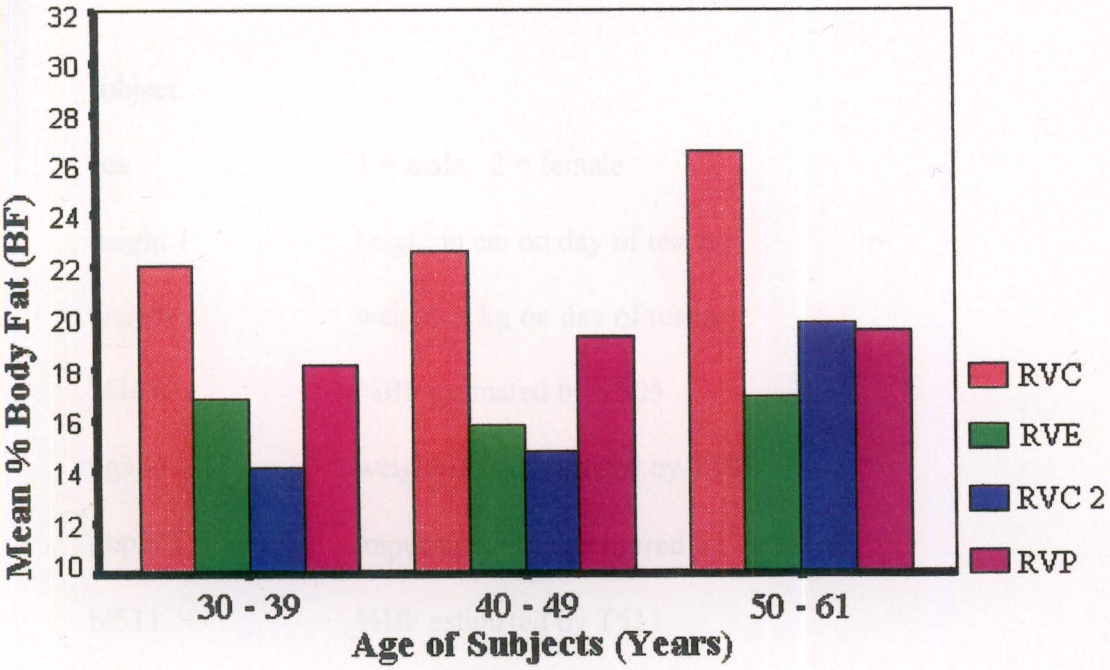


Figure 15

Age-groups: Mean % Body Fat (BF) calculated from RV in Men



Age-groups: Mean % Body Fat (BF) calculated from RV in Women

Figure 16

ABBREVIATIONS USED IN TABLES OF RAW DATA

subject	
sex	1 = male; 2 = female
height 1	height in cm on day of testing
weight 1	weight in kg on day of testing
bf305	%BF estimated by T305
kg305	weight in kg measured by T305
imp305	impedance in Ω measured by T305
bf511	%BF estimated by T511
kg511	weight in kg measured by T511
bfbst	%BF estimated by BS
impbst	impedance in Ω measured by BS
bfss	%BF estimated by SS
bfhw	%BF estimated by D
rvm	RV estimated by oxygen dilution (litres)
vc	VC
rvest	RVC
ht2	height (only re-tested subjects - also for following 6 rows)
wt2	
bf3052	
kg3052	
imp3052	

bf5112	
kg5112	
age	in years
bfrvest	%BF estimated from RVC
rvest2	RVC2
rvp	RVP
bfrvest2	%BF estimated from RVC2
bfrvp	%BF estimated from RVP
bmi	BMI calculated from height1 and weight1
bmibf	%BF estimated from BMI

NOTE: other abbreviations used in the table headed "mean" or "diff" are calculations for Bland & Altman plots; "filter" and "agegroups" refer to data selections for different analyses.

a:\tanita1.sav

	subject	sex	height1	weight1	bf305	kg305	imp305	bf511
1	1.00	1.00	176.30	80.70	22.00	80.60	484.00	23.00
2	2.00	2.00	160.00	50.20	23.00	50.40	547.00	24.00
3	3.00	2.00	166.80	62.80	32.00	62.80	571.00	29.00
4	4.00	1.00	177.50	76.70	19.00	76.80	481.00	19.00
5	5.00	2.00	156.10	58.20	29.00	58.60	458.00	30.00
6	6.00	1.00	171.00	82.30	28.00	82.60	476.00	27.00
7	7.00	2.00	166.30	67.60	30.00	67.80	459.00	30.00
8	8.00	1.00	170.40	75.40	21.00	75.00	461.00	22.00
9	9.00	2.00	157.90	50.50	23.00	50.40	450.00	23.00
10	10.00	1.00	165.50	70.60	22.00	70.40	495.00	23.00
11	11.00	2.00	167.00	62.80	30.00	62.60	540.00	30.00
12	12.00	1.00	173.50	74.00	17.00	73.80	436.00	17.00
13	13.00	2.00	170.00	62.90	26.00	62.60	498.00	27.00
14	14.00	2.00	168.50	61.90	28.00	61.60	531.00	28.00
15	15.00	2.00	165.30	59.40	29.00	59.20	572.00	31.00
16	16.00	2.00	160.30	54.50	27.00	54.40	555.00	28.00
17	17.00	2.00	160.80	56.60	24.00	56.40	580.00	30.00
18	18.00	2.00	168.60	75.60	.	75.20	535.00	.
19	19.00	1.00	172.00	77.50	22.00	77.20	465.00	23.00
20	20.00	1.00	174.30	76.60	19.00	76.40	450.00	20.00
21	21.00	1.00	175.40	78.80	21.00	78.40	470.00	22.00
22	22.00	2.00	164.10	57.10	29.00	57.00	605.00	30.00
23	24.00	1.00	180.80	69.10	12.00	69.00	507.00	12.00
24	25.00	1.00	166.90	63.80	14.00	63.60	439.00	14.00
25	26.00	2.00	156.40	58.00	37.00	57.80	614.00	38.00
26	27.00	1.00	173.00	64.00	12.00	63.80	457.00	12.00
27	28.00	2.00	168.70	61.00	26.00	61.00	519.00	27.00
28	29.00	2.00	175.10	75.80	34.00	75.60	521.00	35.00
29	30.00	2.00	167.80	73.00	39.00	72.80	551.00	40.00
30	31.00	1.00	173.10	62.10	11.00	62.00	489.00	12.00
31	32.00	2.00	168.40	59.20	27.00	58.40	592.00	28.00
32	33.00	1.00	176.40	72.30	16.00	71.40	479.00	16.00
33	34.00	2.00	173.40	73.20	31.00	72.20	490.00	32.00
34	35.00	1.00	173.20	88.20	24.00	87.20	400.00	24.00

	subject	sex	height1	weight1	bf305	kg305	imp305	bf511
35	36.00	2.00	160.50	54.40	24.00	53.80	490.00	24.00
36	37.00	2.00	164.80	58.20	28.00	57.40	582.00	29.00
37	38.00	1.00	170.40	63.50	13.00	62.60	468.00	13.00
38	39.00	2.00	179.80	79.90	16.00	78.80	420.00	17.00
39	40.00	2.00	149.60	55.50	34.00	54.60	531.00	35.00

	kg511	bfbst	impbst	bfss	bfhw	rvm	vc	rvest
1	80.60	21.30	457.00	24.00	12.10	2.30	4.50	1.08
2	50.40	23.70	558.00	20.40	5.00	2.70	3.30	.80
3	63.00	29.10	557.00	27.70	21.10	2.10	3.70	.88
4	76.80	19.40	454.00	23.50	19.20	2.75	4.30	1.03
5	58.40	28.50	533.00	30.40	28.30	1.49	3.40	.86
6	82.60	21.50	458.00	20.50	20.70	1.84	4.40	1.05
7	67.80	28.10	489.00	35.20	16.10	1.91	3.70	.88
8	75.00	23.60	460.00	25.60	18.60	2.86	3.80	.91
9	50.40	18.80	537.00	22.90	4.50	1.72	3.40	.82
10	70.60	20.00	463.00	22.50	17.20	1.80	4.50	1.08
11	62.60	26.40	586.00	28.00	25.70	1.35	3.30	.79
12	74.00	12.30	422.00	18.20	21.10	1.67	5.70	1.37
13	62.80	21.30	501.00	26.20	19.20	2.09	3.80	.91
14	61.60	26.00	573.00	28.10	21.50	1.49	3.80	.91
15	59.20	28.50	616.00	32.30	21.40	1.92	4.50	1.08
16	54.40	22.60	572.00	25.00	18.00	1.83	3.70	.89
17	56.60	27.20	625.00	26.10	31.60	1.38	3.70	.89
18	75.40	.	559.00	39.50	30.00	1.97	3.10	.74
19	77.40	19.70	476.00	23.70	20.10	2.15	4.50	1.08
20	76.60	15.40	420.00	19.30	17.80	1.80	5.10	1.22
21	78.80	19.50	464.00	25.60	24.80	1.81	4.10	.98
22	57.20	26.30	600.00	29.30	22.20	1.60	4.15	.97
23	69.00	12.00	489.00	14.90	10.70	1.90	4.90	1.18
24	63.60	15.40	470.00	20.60	8.40	2.40	5.35	1.28
25	58.00	31.40	644.00	32.90	33.10	1.08	2.95	.71
26	64.00	8.90	438.00	11.20	11.50	2.30	4.60	1.10
27	61.00	22.80	538.00	26.00	17.70	1.72	4.30	1.03
28	75.80	30.60	515.00	33.80	23.10	2.55	2.90	.70
29	73.00	32.30	521.00	41.10	23.00	1.97	3.90	.94
30	62.00	16.30	501.00	16.70	11.00	2.90	5.70	1.37
31	58.40	24.20	629.00	28.30	23.30	1.14	4.20	1.01
32	71.60	22.10	503.00	22.50	13.70	1.87	4.00	.96
33	72.40	27.30	561.00	30.60	32.00	1.68	5.20	1.25
34	87.40	23.50	410.00	30.20	22.80	1.59	4.10	.98

	kg511	bfbst	impbst	bfss	bfhw	rvm	vc	rvest
35	53.80	22.10	522.00	32.30	22.70	1.49	3.10	.74
36	57.40	26.10	625.00	27.40	23.00	1.59	4.20	1.01
37	62.60	17.80	478.00	15.50	15.00	1.86	4.40	1.06
38	79.00	9.50	386.00	15.40	9.10	1.74	5.10	1.22
39	54.80	33.30	531.00	35.90	18.50	2.07	3.10	.74

	ht2	wt2	bf3052	kg3052	imp3052	bf5112	kg5112	age
1	.	.	.	.	.	.	.	52.00
2	.	.	.	.	.	.	.	49.00
3	.	.	.	.	.	.	.	54.00
4	.	.	.	.	.	.	.	56.00
5	156.10	56.50	29.00	57.00	490.00	30.00	57.00	39.00
6	.	.	.	.	.	.	.	34.00
7	.	.	.	.	.	.	.	50.00
8	170.90	75.60	23.00	75.40	497.00	23.00	75.60	60.00
9	.	.	.	.	.	.	.	31.00
10	165.60	71.00	24.00	70.80	511.00	23.00	71.00	42.00
11	166.70	63.70	31.00	63.60	533.00	31.00	63.40	35.00
12	175.00	74.50	18.00	74.00	463.00	18.00	74.20	34.00
13	170.00	62.20	28.00	62.00	55.20	29.00	62.00	46.00
14	168.00	61.50	28.00	61.20	537.00	29.00	61.40	42.00
15	164.70	59.50	33.00	59.20	650.00	34.00	59.60	41.00
16	160.50	54.00	28.00	54.00	576.00	28.00	54.00	37.00
17	160.00	57.50	29.00	57.20	531.00	30.00	57.40	32.00
18	.	.	.	.	.	.	.	50.00
19	171.90	77.80	23.00	77.40	510.00	24.00	77.80	37.00
20	.	.	.	.	.	.	.	42.00
21	.	.	.	.	.	.	.	41.00
22	.	.	.	.	.	.	.	40.00
23	181.80	69.20	11.00	69.40	469.00	12.00	69.60	38.00
24	.	.	.	.	.	.	.	40.00
25	.	.	.	.	.	.	.	49.00
26	.	.	.	.	.	.	.	36.00
27	169.30	61.00	27.00	60.80	540.00	27.00	61.00	44.00
28	.	.	.	.	.	.	.	57.00
29	.	.	.	.	.	.	.	50.00
30	.	.	.	.	.	.	.	49.00
31	.	.	.	.	.	.	.	30.00
32	173.70	72.30	30.00	71.20	503.00	31.00	71.60	61.00
33	.	.	.	.	.	.	.	32.00
34	.	.	.	.	.	.	.	51.00

	ht2	wt2	bf3052	kg3052	imp3052	bf5112	kg5112	age
35	.	.	.	.	.	.	.	40.00
36	.	.	.	.	.	.	.	34.00
37	.	.	.	.	.	.	.	53.00
38	.	.	.	.	.	.	.	34.00
39	179.90	80.20	15.00	79.20	395.00	15.00	79.20	49.00

	bfrvest	mean	diff	agegp	filter_$	rvest2	agegp3	rvp
1	29.97	1.69	1.22	2.00	1	2.07	3.00	1.92
2	23.73	1.75	1.90	2.00	0	1.52	2.00	1.56
3	28.33	1.49	1.22	2.00	0	1.70	3.00	1.77
4	30.26	1.89	1.72	2.00	1	1.98	3.00	2.00
5	33.63	1.18	.63	1.00	0	1.56	1.00	1.33
6	28.48	1.45	.79	1.00	1	2.02	1.00	1.54
7	24.41	1.40	1.03	2.00	0	1.70	3.00	1.69
8	31.45	1.89	1.95	2.00	1	1.75	3.00	1.93
9	13.28	1.27	.90	1.00	0	1.56	1.00	1.24
10	22.22	1.44	.72	1.00	1	2.07	2.00	1.56
11	32.14	1.07	.56	1.00	0	1.52	1.00	1.48
12	15.55	1.52	.30	1.00	1	2.62	1.00	1.58
13	28.46	1.50	1.18	2.00	0	1.75	2.00	1.70
14	26.18	1.20	.58	1.00	0	1.75	2.00	1.61
15	28.39	1.50	.84	1.00	0	2.07	2.00	1.54
16	26.50	1.36	.94	1.00	0	1.70	1.00	1.38
17	27.16	1.14	.49	1.00	0	1.70	1.00	1.31
18	38.03	1.36	1.23	2.00	0	1.43	3.00	1.74
19	29.58	1.62	1.07	1.00	1	2.07	1.00	1.60
20	21.54	1.51	.58	1.00	1	2.35	2.00	1.72
21	28.71	1.40	.83	1.00	1	1.89	2.00	1.73
22	27.67	1.29	.63	1.00	0	1.91	2.00	1.50
23	15.90	1.54	.72	1.00	1	2.25	1.00	1.78
24	17.13	1.84	1.12	1.00	1	2.46	2.00	1.55
25	36.65	.90	.37	2.00	0	1.36	2.00	1.49
26	20.76	1.70	1.20	1.00	1	2.12	1.00	1.60
27	23.26	1.38	.69	1.00	0	1.98	2.00	1.65
28	35.16	1.63	1.85	2.00	0	1.33	3.00	1.97
29	29.97	1.46	1.03	2.00	0	1.79	3.00	1.72
30	23.24	2.13	1.53	2.00	1	2.62	2.00	1.81
31	24.36	1.08	.13	1.00	0	1.93	1.00	1.42
32	20.02	1.42	.91	2.00	1	1.84	3.00	2.06
33	34.93	1.47	.43	1.00	0	2.39	1.00	1.55
34	26.26	1.29	.61	2.00	1	1.89	3.00	1.84

	bfrvest	mean	diff	agegp	filter_$	rvest2	agegp3	rvp
35	29.51	1.12	.75	1.00	0	1.43	2.00	1.43
36	27.91	1.30	.58	1.00	0	1.93	1.00	1.42
37	21.20	1.46	.80	2.00	1	2.02	3.00	1.82
38	12.38	1.48	.52	1.00	0	2.35	1.00	1.70
39	30.42	1.40	1.33	2.00	0	1.43	2.00	1.36

	bfrvest2	bfrvp	bfssm	diffss	meanhwt1	diffhwt1	meanhwt2	diffhwt2
1	19.74	20.66	18.05	11.90	17.05	-9.90	17.55	-10.90
2	21.16	16.23	12.70	15.40	14.00	-18.00	14.50	-19.00
3	24.23	23.68	24.40	6.60	26.55	-10.90	25.05	-7.90
4	24.13	24.00	21.35	4.30	19.10	.20	19.10	.20
5	27.68	29.64	29.35	2.10	28.65	-.70	29.15	-1.70
6	19.65	22.54	20.60	-.20	24.35	-7.30	23.85	-6.30
7	17.67	17.74	25.65	19.10	23.05	-13.90	23.05	-13.90
8	25.89	22.93	22.10	7.00	19.80	-2.40	20.30	-3.40
9	6.03	9.17	13.70	18.40	13.75	-18.50	13.75	-18.50
10	15.28	18.90	19.85	5.30	19.60	-4.80	20.10	-5.80
11	24.86	25.18	26.85	2.30	27.85	-4.30	27.85	-4.30
12	6.72	13.68	19.65	-2.90	19.05	4.10	19.05	4.10
13	21.85	22.24	22.70	7.00	22.60	-6.80	23.10	-7.80
14	19.47	20.59	24.80	6.60	24.75	-6.50	24.75	-6.50
15	20.14	24.56	26.85	10.90	25.20	-7.60	26.20	-9.60
16	19.14	22.91	21.50	7.00	22.50	-9.00	23.00	-10.00
17	20.07	23.49	28.85	-5.50	27.80	7.60	30.80	1.60
18	33.51	31.48	34.75	9.50	.	.	.	.
19	23.25	26.25	21.90	3.60	21.05	-1.90	21.55	-2.90
20	14.24	18.31	18.55	1.50	18.40	-1.20	18.90	-2.20
21	22.99	24.00	25.20	.80	22.90	3.80	23.40	2.80
22	19.72	23.67	25.75	7.10	25.60	-6.80	26.10	-7.80
23	8.23	11.60	12.80	4.20	11.35	-1.30	11.35	-1.30
24	7.98	15.04	14.50	12.20	11.20	-5.60	11.20	-5.60
25	31.10	29.99	33.00	-.20	35.05	-3.90	35.55	-4.90
26	12.87	16.89	11.35	-.30	11.75	-.50	11.75	-.50
27	15.55	18.23	21.85	8.30	21.85	-8.30	22.35	-9.30
28	31.06	26.88	28.45	10.70	28.55	-10.90	29.05	-11.90
29	24.21	24.68	32.05	18.10	31.00	-16.00	31.50	-17.00
30	13.28	19.74	13.85	5.70	11.00	.00	11.50	-1.00
31	16.66	20.93	25.80	5.00	25.15	-3.70	25.65	-4.70
32	13.99	12.49	18.10	8.80	14.85	-2.30	14.85	-2.30
33	27.22	32.90	31.30	-1.40	31.50	1.00	32.00	.00
34	21.16	21.44	26.50	7.40	23.40	-1.20	23.40	-1.20

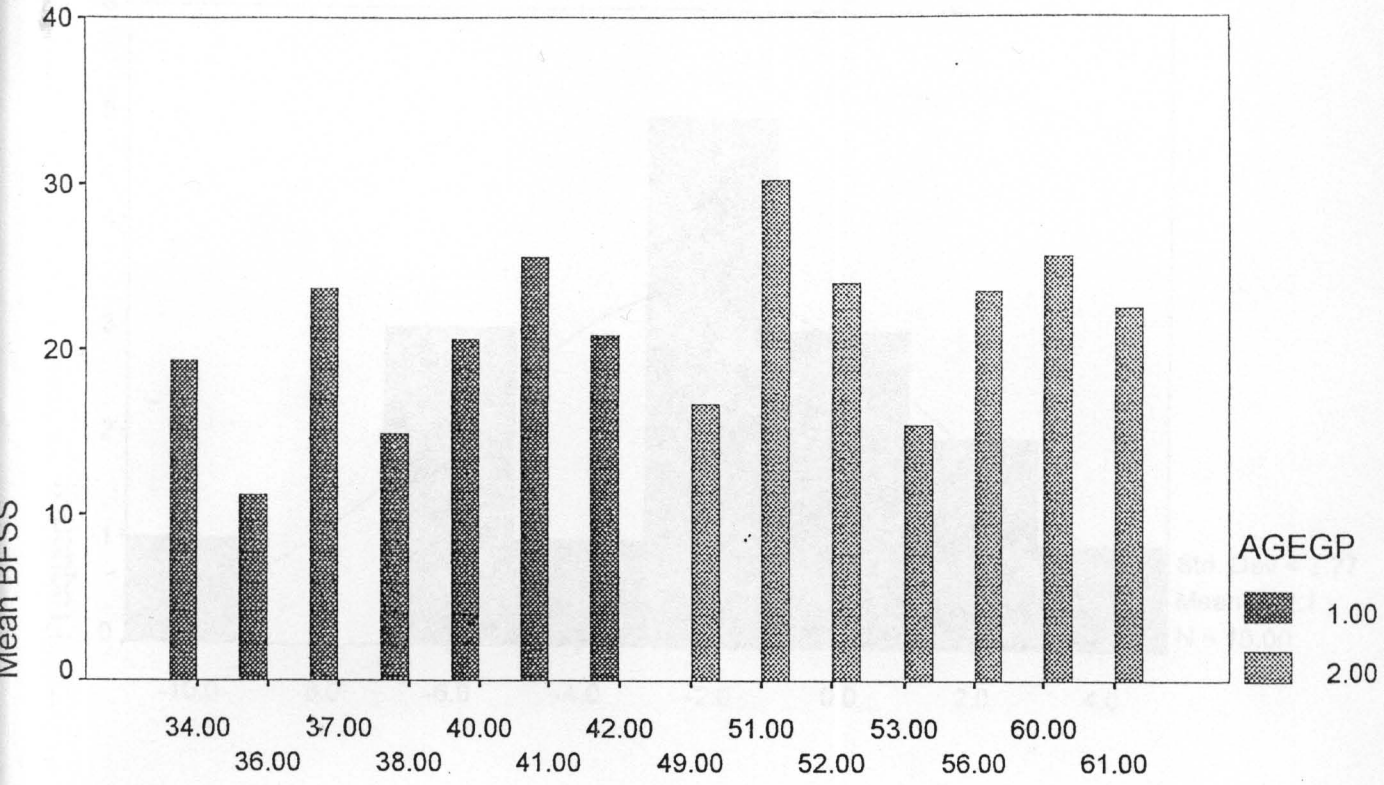
	bfrvest2	bfrvp	bfssm	diffss	meanhwt1	diffhwt1	meanhwt2	diffhwt2
35	23.23	23.23	27.50	9.60	23.35	-1.30	23.35	-1.30
36	20.09	24.68	25.20	4.40	25.50	-5.00	26.00	-6.00
37	13.71	15.27	15.25	.50	14.00	2.00	14.00	2.00
38	4.39	9.41	12.25	6.30	12.55	-6.90	13.05	-7.90
39	23.36	23.99	27.20	17.40	26.25	-15.50	26.75	-16.50

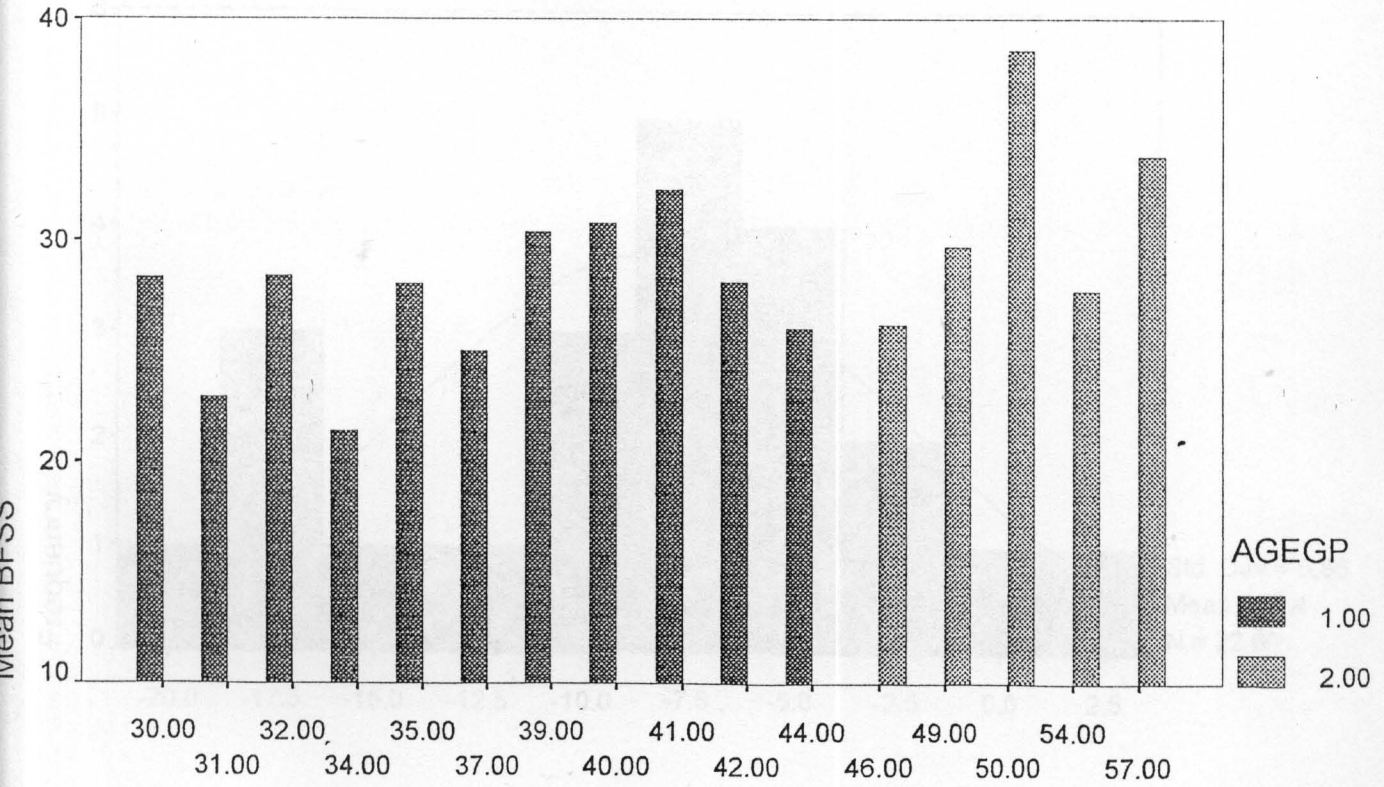
	meanhwbs	diffhwbs	meanhwss	diffhwss	bmi	bmibf	meanhwbm	diffhwbm
1	16.70	-9.20	18.05	-11.90	25.96	26.92	19.51	-14.82
2	14.35	-18.70	12.70	-15.40	19.61	29.40	17.20	-24.40
3	25.10	-8.00	24.40	-6.60	22.57	21.69	21.40	-.59
4	19.30	-.20	21.35	-4.30	24.34	25.89	22.55	-6.69
5	28.40	-.20	29.35	-2.10	23.88	32.23	30.27	-3.93
6	21.10	-.80	20.60	.20	28.14	25.39	23.05	-4.69
7	22.10	-12.00	25.65	-19.10	24.44	35.43	25.77	-19.33
8	21.10	-5.00	22.10	-7.00	25.97	28.76	23.68	-10.16
9	11.65	-14.30	13.70	-18.40	20.25	26.04	15.27	-21.54
10	18.60	-2.80	19.85	-5.30	25.76	24.39	20.80	-7.19
11	26.05	-.70	26.85	-2.30	22.52	29.67	27.69	-3.97
12	16.70	8.80	19.65	2.90	24.58	21.12	21.11	-.02
13	20.25	-2.10	22.70	-7.00	21.76	31.30	25.25	-12.10
14	23.75	-4.50	24.80	-6.60	21.80	30.42	25.96	-8.92
15	24.95	-7.10	26.85	-10.90	21.74	30.12	25.76	-8.72
16	20.30	-4.60	21.50	-7.00	21.21	28.56	23.28	-10.56
17	29.40	4.40	28.85	5.50	21.89	28.23	29.92	3.37
18	.	.	34.75	-9.50	26.59	38.01	34.00	-8.01
19	19.90	.40	21.90	-3.60	26.20	23.75	21.93	-3.65
20	16.60	2.40	18.55	-1.50	25.21	23.72	20.76	-5.92
21	22.15	5.30	25.20	-.80	25.61	23.97	24.39	.83
22	24.25	-4.10	25.75	-7.10	21.20	29.24	25.72	-7.04
23	11.35	-1.30	12.80	-4.20	21.14	17.91	14.31	-7.21
24	11.90	-7.00	14.50	-12.20	22.90	20.48	14.44	-12.08
25	32.25	1.70	33.00	.20	23.71	34.32	33.71	-1.22
26	10.20	2.60	11.35	.30	21.38	17.74	14.62	-6.24
27	20.25	-5.10	21.85	-8.30	21.43	30.44	24.07	-12.74
28	26.85	-7.50	28.45	-10.70	24.72	37.34	30.22	-14.24
29	27.65	-9.30	32.05	-18.10	25.93	37.21	30.11	-14.21
30	13.65	-5.30	13.85	-5.70	20.72	19.94	15.47	-8.94
31	23.75	-.90	25.80	-5.00	20.87	26.55	24.93	-3.25
32	17.90	-8.40	18.10	-8.80	23.23	25.71	19.70	-12.01
33	29.65	4.70	31.30	1.40	24.34	31.17	31.59	.83
34	23.15	-.70	26.50	-7.40	29.40	30.81	26.81	-8.01

	meanhwbs	diffhwbs	meanhwss	diffhwss	bmi	bmibf	meanhwbm	diffhwbm
35	22.40	.60	27.50	-9.60	21.12	29.14	25.92	-6.44
36	24.55	-3.10	25.20	-4.40	21.43	28.13	25.57	-5.13
37	16.40	-2.80	15.25	-.50	21.87	22.23	18.62	-7.23
38	9.30	-.40	12.25	-6.30	24.71	32.08	20.59	-22.98
39	25.90	-14.80	27.20	-17.40	24.80	35.63	27.07	-17.13

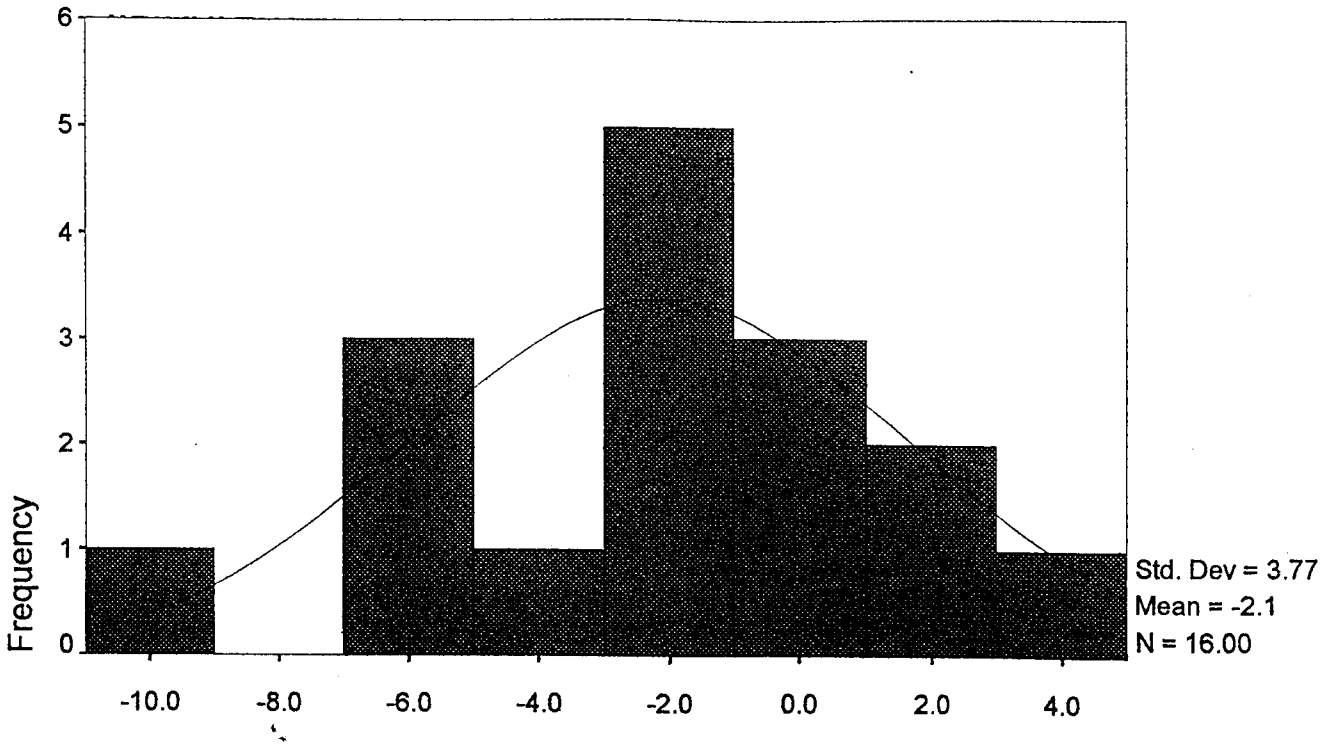
	meanbmt1	diffbmt1	meanbmt2	diffbmt2
1	24.46	4.92	24.96	3.92
2	26.20	6.40	26.70	5.40
3	26.85	-10.31	25.35	-7.31
4	22.45	6.89	22.45	6.89
5	30.62	3.23	31.12	2.23
6	26.70	-2.61	26.20	-1.61
7	32.72	5.43	32.72	5.43
8	24.88	7.76	25.38	6.76
9	24.52	3.04	24.52	3.04
10	23.20	2.39	23.70	1.39
11	29.84	-.33	29.84	-.33
12	19.06	4.12	19.06	4.12
13	28.65	5.30	29.15	4.30
14	29.21	2.42	29.21	2.42
15	29.56	1.12	30.56	-.88
16	27.78	1.56	28.28	.56
17	26.12	4.23	29.12	-1.77
18	.	.	.	.
19	22.88	1.75	23.38	.75
20	21.36	4.72	21.86	3.72
21	22.49	2.97	22.99	1.97
22	29.12	.24	29.62	-.76
23	14.96	5.91	14.96	5.91
24	17.24	6.48	17.24	6.48
25	35.66	-2.68	36.16	-3.68
26	14.87	5.74	14.87	5.74
27	28.22	4.44	28.72	3.44
28	35.67	3.34	36.17	2.34
29	38.11	-1.79	38.61	-2.79
30	15.47	8.94	15.97	7.94
31	26.78	-.45	27.28	-1.45
32	20.86	9.71	20.86	9.71
33	31.09	.17	31.59	-.83
34	27.41	6.81	27.41	6.81

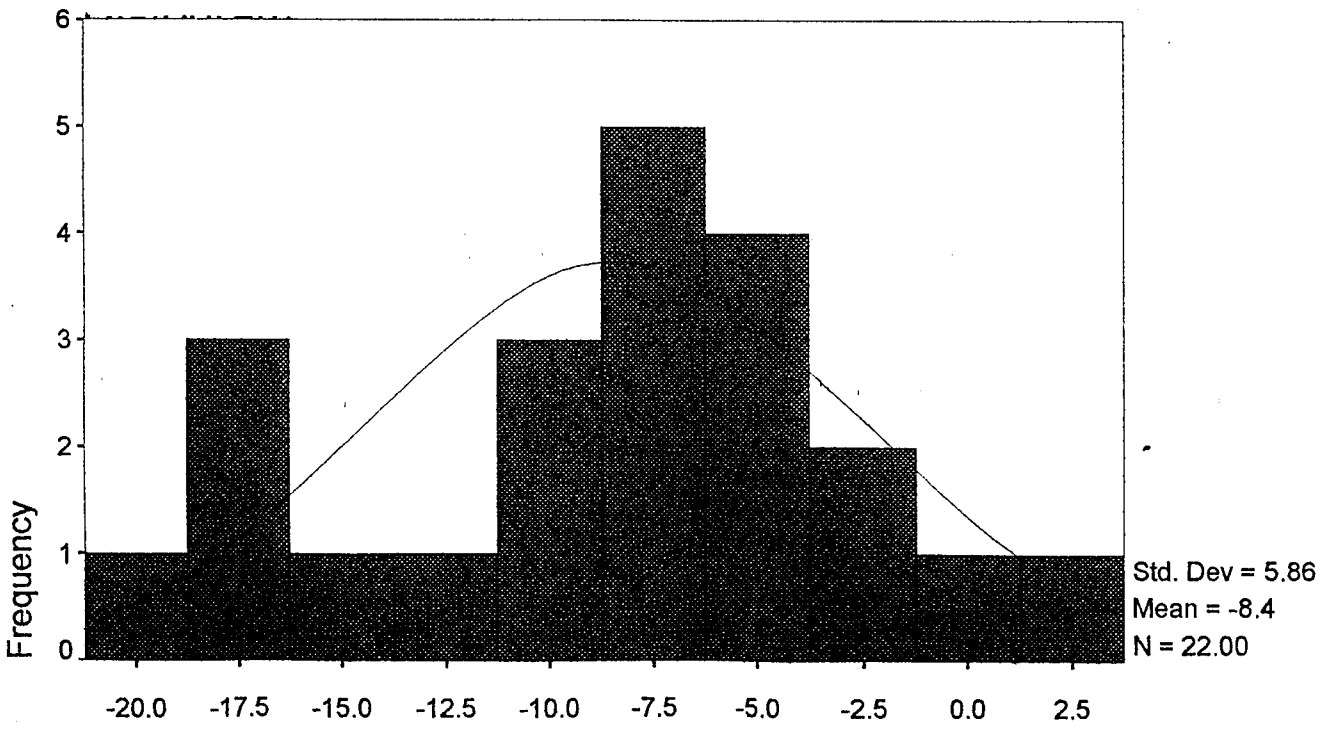
	meanbmt1	diffbmt1	meanbmt2	diffbmt2
35	26.57	5.14	26.57	5.14
36	28.07	.13	28.57	-.87
37	17.62	9.23	17.62	9.23
38	24.04	16.08	24.54	15.08
39	34.82	1.63	35.32	.63



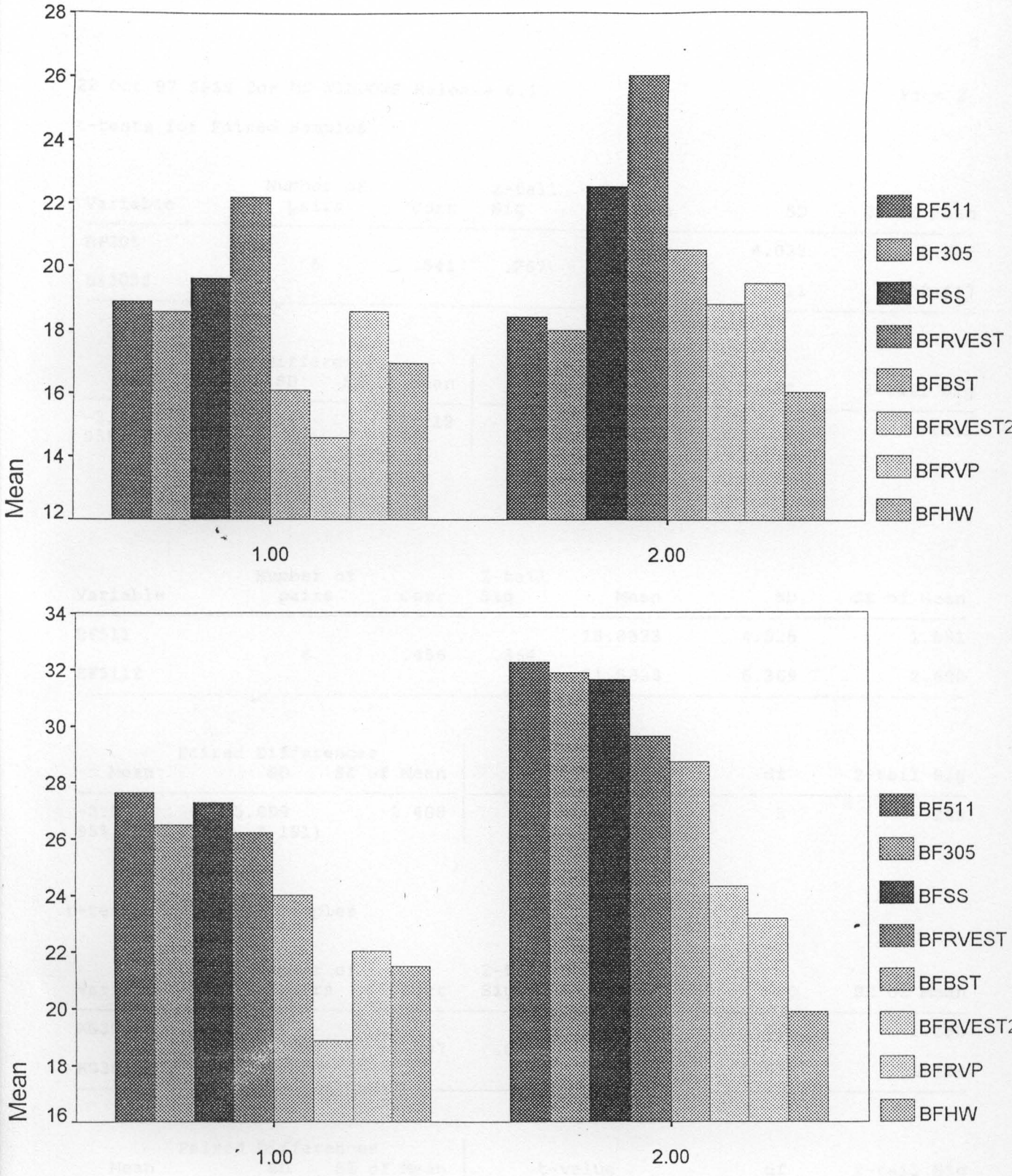


Appendix Sample Graphs 1: Mean SS by age; male subjects above.
Note gradually increasing %BF with age for both male and female subjects.
Age groups: 1 = 30 - 45; 2 = 46 -61.





Appendix Sample Graphs 2: Normal frequency distributions of mean difference of %BF.
Above: Male subjects D with T511
Below: Female subjects D with T511.



Appendix Sample Graphs 3: Differences in mean %BF estimations by method + RVdifferences.
Males subjects above.
Note order of %BF estimations for women: Tanita method estimates are highest when sample divided by age. (NB BMI calculations not included). Effect of different RV calculations is also noticable. RVEST = RVC and RVEST2 = RVC2 from main text. Age groups: 1 = 30 - 45; 2 = 46 - 61.

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF305	6	.541	.267	18.3333	4.033	1.647
BF3052				21.5000	6.411	2.617

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-3.1667	5.419	2.212	-1.43	5	.212
95% CI (-8.854, 2.520)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	6	.456	.364	18.8333	4.535	1.851
BF5112				21.8333	6.369	2.600

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-3.0000	5.899	2.408	-1.25	5	.268
95% CI (-9.191, 3.191)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
KG305	6	.997	.000	72.8000	3.078	1.256
KG3052				73.0333	3.071	1.254

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.2333	.234	.095	-2.44	5	.058

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	23	.818	.000	21.3087	7.627	1.590
BFRVEST				27.9330	6.288	1.311

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-6.6243	4.386	.915	-7.24	22	.000
95% CI (-8.521, -4.728)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF305	9	-.578	.103	28.1111	2.892	.964
BF3052				27.5556	5.053	1.684

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
.5556	7.126	2.375	.23	8	.821
95% CI (-4.922, 6.033)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	9	-.570	.109	29.5556	2.506	.835
BF5112				28.1111	5.302	1.767

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.4444	7.038	2.346	.62	8	.555
95% CI (-3.965, 6.854)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
KG305	9	-.126	.746	59.0000	3.243	1.081
KG3052				61.5778	7.235	2.412

Mean	30.972	Std dev	3.977	Skewness	-.001
S E Skew	.481	Range	16.320		

Valid cases 23 Missing cases 0

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	9	-.570	.109	29.5556	2.506	.835
BF5112				28.1111	5.302	1.767

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.4444	7.038	2.346	.62	8	.555
95% CI (-3.965, 6.854)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	6	.456	.364	18.8333	4.535	1.851
BF5112				21.8333	6.369	2.600

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-3.0000	5.899	2.408	-1.25	5	.268
95% CI (-9.191, 3.191)					

- - Correlation Coefficients - -

	BFHW	BFBST
BFHW	1.0000	.4426
	(16)	(16)
	P= .	P= .086
BFBST	.4426	1.0000
	(16)	(16)
	P= .086	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	BFHW	BFSS
BFHW	1.0000	.5909
	(16)	(16)
	P= .	P= .016
BFSS	.5909	1.0000
	(16)	(16)

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BMIBF	BF305
BMIBF	1.0000	.7680
	(16)	(16)
	P= .	P= .001
BF305	.7680	1.0000
	(16)	(16)
	P= .001	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BFHW	BFBST
BFHW	1.0000	.5812
	(23)	(22)
	P= .	P= .005
BFBST	.5812	1.0000
	(22)	(22)
	P= .005	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BFHW	BFSS
BFHW	1.0000	.5591
	(23)	(23)
	P= .	P= .006
BFSS	.5591	1.0000
	(23)	(23)
	P= .006	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BFHW	BF305
BFHW	1.0000	.5436
	(23)	(22)
	P= .	P= .009
BF305	.5436	1.0000
	(22)	(22)
	P= .009	P= .

```
            P= .016     P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

                        - -  Correlation Coefficients  - -

              BFHW        BF305

BFHW          1.0000       .7109
             (   16)     (   16)
             P= .        P= .002

BF305          .7109      1.0000
             (   16)     (   16)
             P= .002     P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

                        - -  Correlation Coefficients  - -

              BFHW        BF511

BFHW          1.0000       .7096
             (   16)     (   16)
             P= .        P= .002

BF511          .7096      1.0000
             (   16)     (   16)
             P= .002     P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

                        - -  Correlation Coefficients  - -

              BFHW        BMIBF

BFHW          1.0000       .5666
             (   16)     (   16)
             P= .        P= .022

BMIBF          .5666      1.0000
             (   16)     (   16)
             P= .022     P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

                        - -  Correlation Coefficients  - -

              BMIBF       BF511

BMIBF         1.0000       .7766
             (   16)     (   16)
             P= .        P= .000

BF511          .7766      1.0000
             (   16)     (   16)
             P= .000     P= .
```

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BFHW	BF511
BFHW	1.0000	.6332
	(23)	(22)
	P= .	P= .002
BF511	.6332	1.0000
	(22)	(22)
	P= .002	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BFHW	BMIBF
BFHW	1.0000	.2271
	(23)	(23)
	P= .	P= .297
BMIBF	.2271	1.0000
	(23)	(23)
	P= .297	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BMIBF	BF305
BMIBF	1.0000	.4527
	(23)	(22)
	P= .	P= .034
BF305	.4527	1.0000
	(22)	(22)
	P= .034	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

20 Oct 97 SPSS for MS WINDOWS Release 6.1

- - Correlation Coefficients - -

	BMIBF	BF511
BMIBF	1.0000	.5223
	(23)	(22)
	P= .	P= .013
BF511	.5223	1.0000
	(22)	(22)
	P= .013	P= .

BFHW	16	.591	.016	16.5438	4.886	1.222
BFSS				20.9062	4.810	1.202

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
-4.3625	4.386	1.096	-3.98	15	.001
95% CI (-6.699, -2.026)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFBST	16	.443	.086	18.0438	4.323	1.081
BFHW				16.5438	4.886	1.222

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.5000	4.886	1.221	1.23	15	.238
95% CI (-1.103, 4.103)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF305	16	.711	.002	18.3125	4.963	1.241
BFHW				16.5438	4.886	1.222

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.7687	3.745	.936	1.89	15	.078
95% CI (-.227, 3.765)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	16	.710	.002	18.6875	5.003	1.251
BFHW				16.5438	4.886	1.222

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
2.1437	3.770	.942	2.27	15	.038
95% CI (.135, 4.152)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	16	.567	.022	16.5438	4.886	1.222
BMIBF				23.6706	3.662	.915

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-7.1269	4.124	1.031	-6.91	15	.000
95% CI (-9.324, -4.929)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF305	16	.768	.001	18.3125	4.963	1.241
BMIBF				23.6706	3.662	.915

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-5.3581	3.182	.795	-6.74	15	.000
95% CI (-7.054, -3.663)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	16	.777	.000	18.6875	5.003	1.25
BMIBF				23.6706	3.662	.91

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Si
-4.9831	3.160	.790	-6.31	15	.00
95% CI (-6.667, -3.299)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mea
BF511	16	.777	.000	18.6875	5.003	1.25
BMIBF				23.6706	3.662	.91

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Si
-4.9831	3.160	.790	-6.31	15	.00
95% CI (-6.667, -3.299)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	16	.490	.054	16.5438	4.886	1.222
BFRVEST				23.8919	5.396	1.349

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-7.3481	5.214	1.303	-5.64	15	.000
95% CI (-10.126, -4.570)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	16	.490	.054	16.5438	4.886	1.222
BFRVEST				23.8919	5.396	1.349

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-7.3481	5.214	1.303	-5.64	15	.000
95% CI (-10.126, -4.570)					

t-tests for Paired Samples

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
.2180	.332	.069	3.15	22	.005
95% CI (.074, .362)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
RVM	16	.314	.236	2.1125	.427	.107
RVP				1.7523	.169	.042

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
.3602	.407	.102	3.54	15	.003
95% CI (.143, .577)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	23	.559	.006	21.3087	7.627	1.590
BFSS				29.3391	5.833	1.216

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-8.0304	6.515	1.358	-5.91	22	.000
95% CI (-10.848, -5.213)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFBST	22	.581	.005	25.7318	5.179	1.104
BFHW				20.9136	7.561	1.612

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
4.8182	6.203	1.323	3.64	21	.002
95% CI (2.068, 7.569)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF305	22	.544	.009	28.4545	5.078	1.083
BFHW				20.9136	7.561	1.612

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
7.5409	6.420	1.369	5.51	21	.000
95% CI (4.694, 10.387)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	22	.633	.002	29.3182	5.027	1.072
BFHW				20.9136	7.561	1.612

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig

8.4045	5.857	1.249	6.73	21	.000
95% CI (5.808, 11.001)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	23	.227	.297	21.3087	7.627	1.590
BMIBF				30.9717	3.977	.829

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
-9.6630	7.759	1.618	-5.97	22	.000
95% CI (-13.018, -6.308)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BFHW	23	.227	.297	21.3087	7.627	1.590
BMIBF				30.9717	3.977	.829

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
-9.6630	7.759	1.618	-5.97	22	.000
95% CI (-13.018, -6.308)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF305	22	.453	.034	28.4545	5.078	1.083
BMIBF				30.6518	3.756	.801

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig
-2.1973	4.756	1.014	-2.17	21	.042
95% CI (-4.306, -.089)					

t-tests for Paired Samples

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
BF511	22	.522	.013	29.3182	5.027	1.072
BMIBF				30.6518	3.756	.801

Paired Differences					
Mean	SD	SE of Mean	t-value	df	2-tail Sig

Males

- - - - - O N E W A Y - - - - -

Variable RVEST
By Variable AGEGP

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.1059	.0530	3.6862	.0539
Within Groups	13	.1867	.0144		
Total	15	.2926			

- - - - - O N E W A Y - - - - -

Variable RVM
By Variable AGEGP

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0849	.0425	.2082	.8147
Within Groups	13	2.6524	.2040		
Total	15	2.7373			

- - - - - O N E W A Y - - - - -

Variable DIFF
By Variable AGEGP

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.3793	.1896	.9758	.4029
Within Groups	13	2.5263	.1943		
Total	15	2.9056			

Hi-Res Chart # 3:Line of mean(rvest rvm) by age

- - - - - O N E W A Y - - - - -

RVE differences by age
Female subjects

Variable DIFF
By Variable AGEGP

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
etween Groups	2	1.9254	.9627	8.0350	.0027
ithin Groups	20	2.3963	.1198		
otal	22	4.3217			

- - - - - O N E W A Y - - - - -

Variable DIFF
By Variable AGEGP

ultiple Range Tests: Tukey-HSD test with significance level .050

he difference between two means is significant if
MEAN(J)-MEAN(I) >= .2448 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 3.57

(*) Indicates significant differences which are shown in the lower triangle

Mean	AGEGP	G r p 1	G r p 2	G r p 3
.5964	Grp 1			
1.0180	Grp 2	*		
1.5350	Grp 3	*		

Reference

Proceedings of the XXXIII Int. Cong. Physiol. Sci. (1997)

P029.04

RESIDUAL VOLUME AND VITAL CAPACITY IN ACTIVE 30-60 YEAR OLDS, AND THEIR RELATION TO BODY FAT ESTIMATES

By Cotterrell, D, Irving, K and Sykes, K.

Department of P.E and Sports Science, University College Chester, Chester CH1 4BJ, United Kingdom.

APPENDIX D

ADDITIONAL MATERIALS

This appendix contains copies of the documents produced in order to conduct this study: a promotional poster, letters to volunteer subjects, Informed Consent and data collection forms and the Activity Questionnaire.

This Appendix also contains a sample of the promotional literature produced by the manufacturers of the BIA scales tested in this study.

WE NEED YOU!

- are you aged between 18 and 60?

- could you spare an hour or so between mid-June and mid-July 1996?

One hundred adults are needed to help with a research project at University College, Chester, where a new method of measuring "body composition" is being evaluated. Volunteers will need to attend the College on one occasion for some body measurements to be taken: appointments can be arranged during the day or on weekday evenings. The results of this project will be of use to health and sports science professionals, as well as providing data for 2 MSc dissertations: your participation would be much appreciated. In return, the researchers will be pleased to answer any questions you may have about exercise and nutrition when you come for your appointment.

- still interested?

Please put your name and contact number or address in the envelope below: full details will be sent to you in early June.

If you would like more information now, please telephone Kate Irving (01244 301536) or Carolyn Perry (01244 327461).

Department of Physical Education and Sports Science,
University College Chester, Cheyne Road, Chester CH1 4BJ

6 Weaver Grove, Mickle Trafford, Chester, CH2 4DW
01244 301536

Date as postmarked

Dear

UNIVERSITY COLLEGE CHESTER

DEPARTMENT OF P.E. AND SPORTS SCIENCE

Thank you for volunteering to be a subject for my research project. This letter is to give you some more information about what will be involved.

University College Chester is testing a new piece of equipment which is designed to estimate a person's body fat. To find out how well this new equipment performs, we are going to estimate body fat in about 100 individuals using the new method and 3 other well established methods. By comparing results from the new method with each of the other methods, we will be able to say how useful this equipment may be. The equipment could be sold to health clubs, hospitals, slimming clubs, occupational health departments and sports centres, so it is important for us to be able to comment on its suitability as fully as possible. Your help, by volunteering to be a subject, is vital and is very much appreciated.

We will allow one and a half hours for each appointment. This will enable us to do all the testing we need and will also give time for you to complete a simple questionnaire, to help us estimate your level of physical activity. The new equipment we are testing looks very much like a pair of electronic bathroom scales, and is quick to use. The other methods take a little longer. "Bodystat" estimates body fat electronically and involves the subject lying comfortably on the floor for 5 minutes, whilst electrodes are attached to the wrist and ankle: its quite painless and is completely safe. Next, skinfold measures will be taken from 4 areas: the back and front of the right upper arm, under the right shoulder blade and just above the hip bone on the right side of the body. Lastly, we will be using hydrostatic weighing, where you will spend about half an hour sitting on a seat in a tank of warm water (approx. 36°C). Firstly, we will measure the air in your lungs whilst you breathe in and out and then your weight will be recorded whilst you are submerged for a few seconds under water. We allow plenty of time for you to get used to bobbing up and down in the water: most people find it very relaxing. If however, you are not confident in water, please let me know.

There are a few important conditions which you **must** adhere to before you come for your appointment. These are to ensure that our measurements are taken under suitable and controlled conditions. Please remember:

- no alcohol or caffeine (tea or coffee) for 24 hours before the appointment
- no exercise for 12 hours before the appointment
- no eating or drinking for 4 hours before the appointment

If you are taking any diuretic medicine (to reduce body water content) during the 7 days before your appointment, I regret that you will not be able to take part in the study as the effect of these drugs will alter the measurements we are making. Unfortunately, if you have not met all these conditions when you come for your appointment, we will not be able to use your measurements.

It would be a good idea to bring a drink and a snack with you to have after your appointment.

The testing will be done in a comfortable room which is next to the College fitness suite. You will need to bring swimwear and a large towel, and for women, if you do not have a bikini-style costume, shorts and a loose fitting T-shirt **in addition**. This is to enable the skin fold measurements to be taken. You will be asked to have a shower before the hydrostatic weighing: there are good shower and changing facilities in the fitness suite. Please bring a bath robe and hairdryer if you wish.

We have planned the testing carefully to make sure that you will feel as confident as possible. I realise that for most of you, the surroundings will be new, and that you may feel a little hesitant about the testing. Please ask about any aspect of the work which interests you, and of course, do raise any queries you have about the testing procedure. I will also be asking you to return for a brief visit to repeat the measurements taken on the new scales. This needs to be done within 14 days of the original test and under the same conditions but will only take 10 minutes.

I enclose a copy of the consent form which you will be asked to sign when you come for your appointment, and a map to show you how to find the fitness suite at the College.

Once again, many thanks for your interest and co-operation.

Yours sincerely,

Enc. (2)

UNIVERSITY COLLEGE CHESTER

DEPARTMENT OF P.E. AND SPORTS SCIENCE

AN INVESTIGATION INTO THE VALIDITY OF PERCENTAGE BODY FAT ESTIMATIONS BY A NEW BIOIMPEDANCE ANALYSER

1. Catherine Irving, who is an MSc student, has requested my participation in a research study at University College, Chester. The title of the research is "An investigation into the validity of percentage body fat estimations by a new bioimpedance analyser".

2. I have been informed that the purpose of the research is to compare the measurements from this new analyser with other methods of percentage body fat estimation, using a sample from the adult population.

3. My participation will involve having my percentage body fat estimated by the following methods: bioelectrical impedance, sum of skinfolds and by hydrostatic weighing. I understand that the time involved to do this will be in the region of 1 hour 30 minutes, and that I will be given a specific time to attend for my appointment.

4. I understand that there are no foreseeable risks to me but that there may be some slight discomfort to me if I agree to participate in this study. The possible discomfort I may experience is slight pressure on the chest during expiration in underwater weighing.

5. There are no feasible alternative procedures available for this study.

6. I understand that the possible benefits of my participation in this research are to develop understanding of this new method of estimating percentage body fat and to increase awareness of the needs of adult volunteer subjects in such studies. I understand that the researcher will provide an explanation of the usefulness and limitations of such measurements.

7. I understand that the results of the research study may be published but that my name or identity will not be revealed. In order to maintain confidentiality of my records, Catherine Irving will use a code number for each subject's records, and that the name of the person to whom each code applies will only be seen by the researcher or by those members of academic staff who need to view results for the purposes of awarding the MSc degree.

8. I have been advised that the research in which I will be participating does not involve more than minimal risk.

9. I have been informed that I will not be compensated for my participation.

10. I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by Catherine Irving, 6 Weaver Grove, Mickle Trafford, Chester, CH2 4DW, telephone Chester (01244) 301536, or by her academic supervisor, Mr. A. Williams, Department of P.E. and Sports Science, University College Chester, CH1 4BJ, telephone Chester (01244) 375444 x 2345.

11. I understand that in case of injury, if I have questions about my rights as a subject/participant in this research, or if I feel I have been placed at risk, I can contact the Chair of the University College Chester Ethics Committee.

12. I have read the above information. The nature, demands, risks and benefits of the project have been explained to me. I knowingly assume the risks involved, and understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form, I am not waiving any legal claims, rights, or remedies. A copy of this consent form will be given to me.

Subject's signature Date

Subject's name (printed please)

13. I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, I have answered any questions that have been raised, and have witnessed the above signature.

14. These elements of informed consent conform to the Assurance given by University College Chester to the Department of P.E. and Sports Science to protect the rights of human subjects.

15. I have provided the subject/participant with a copy of this signed consent document.

Signature of investigator Date

(Catherine M. A. Irving)

ACTIVITY QUESTIONNAIRE SUBJECT NUMBER

This questionnaire is to help us find out how active you are in your everyday life. We need to know about this because the equipment we are testing calculates estimations of body fat according to how active you are.

You will see that you have been asked to say how many times in the last 4 weeks you have been involved in each activity for more than 20 minutes. You may find it easier to work out how many times you have done each activity every week and multiply this number by 4.

Please ask if you are not sure how to answer any of the questions.

SECTION I - ACTIVITY EXCLUDING SPORT.

These questions relate to your everyday life, occupation (whether it is paid, unpaid or voluntary work) and hobbies.

1. Occupation

a) How many times in the past 4 weeks has your occupation been physically demanding for 20 minutes or more?

(Examples would include heavy or moderate manual jobs, caring work such as pushing a wheelchair or double buggy, heavy housework, etc.)

2. Recreation

How many times in the past 4 weeks have your recreational activities (excluding sport) been physically demanding for 20 minutes or more?

(Examples include digging the garden, heavy DIY etc.)

SECTION II - SPORTING ACTIVITIES

How many times in the past 4 weeks have you been involved in any of the following activities for 20 minutes or more?

Write the number of occasions next to each activity.

Walking briskly	Cycling	Swimming
Tennis	Table tennis	Squash

Badminton	Football	Rugby
Cricket	Rounders	Hockey
Netball	Volley Ball	Basketball
Golf	Bowls	Boxing
Martial Arts	Yoga	Gymnastics
Exercises	Keep fit	Aerobics
Dancing for fitness	Ballet/Tap	Country dancing
Social dancing	Aqua-aerobics	Jogging/Running
Athletics	Rambling	Hiking/Backpacking
Climbing	Horse riding	Skiing
Ice Skating	Roller Skating	Circuit Training
Rowing	Sailing	Canoeing

Cycling or rowing ergometry

Any other sporting activities? - please list

It would help us to know your main occupation(s) and sporting activities, if you have any.

a) Occupation(s)

b) Sports

Any comments about this questionnaire?

Thank you very much for your help.

SUBJECT NUMBER .....

HEIGHT	WEIGHT	SEX	AGE

BIA - BODYSTAT		% fat	impedence
BIA - TANITA 305	weight	%fat	impedence
BIA - TANITA 511	weight	%fat	

NB attach TBF-305 print-out

SUM OF SKINFOLDS

				Median
Biceps	_____	_____	_____	_____
Triceps	_____	_____	_____	_____
Subscapular	_____	_____	_____	_____
Suprailiac	_____	_____	_____	_____

SS = ...

Calculations

Men: 1.1610 - 0.0632 x logSS = body density (Durin and Womersley, 1974)
Women: 1.1581 - 0.0720 x logSS = body density (as above)

% fat (Siri, 1956) = [(4.95/body density) - 4.5] x 100

Body density = ... - ..... =

% fat = ...

Durnin & Womersley (1974) SUM 4 Calculations

$D_B = c - (m \times \log SUM)$

AGE →	17-19	20-29	30-39	40-49	50+
MALES					
c	1.1620	1.1631	1.1422	1.1620	1.1715
m	0.0630	0.0632	0.0544	0.0700	0.0779
FEMALES					
c	1.1549	1.1599	1.1423	1.1333	1.1339
m	0.0678	0.0717	0.0632	0.0612	0.0645

$$\% \text{ fat (Siri)} = \frac{495}{D_B} - 450$$

$$= \frac{495}{.....} - 450 = ...$$

DENSITOMETRY

Ambient Temperature (T) = ...°C Barometric Pressure = mmHg

Measurement of Residual Volume

Vital Capacity (VC) = 80% = 90 % = Vol used =

Volume in tubing =

Total volume O_2 in rebreathing bag = (..... + ...) =

Dead space from mouthpiece to valve =

RV = observed Residual Volume

VO_2 = volume of O_2 measured into the anasthetic bag

DS = dead space of mouthpeice and breathing valve

BTPS - correction factors: see attached sheet

$$RV = \frac{VO_2 \times [100\% - (\%O_2 + \%CO_2)]/100}{0.798 - [100\% - (\%O_2 - \%CO_2)]/100} - DS \times BTPS$$

Trial 1 $\%O_2$ = $\%CO_2$ =

$$RV = \frac{\text{.....}[100 - (\text{.....} + \text{.....})]}{79.8 - [100 - (\text{.....} + \text{.....})]} - \text{.....} \times \text{.....}$$

$$= \frac{\text{.....}[100 - \text{.....}]}{79.8 - [100 - \text{.....}]} - \text{.....}$$

$$= \frac{\text{.....} \times \text{.....}}{79.8 - \text{.....}} - \text{.....}$$

$$= \frac{\text{.....}}{\text{.....}} - \text{.....} \qquad = \text{.....} - \text{.....}$$

$$= \text{.....}$$

Trial 2 $\%O_2$ = $\%CO_2$ =

$$RV = \frac{\text{.....}[100 - (\text{.....} + \text{.....})]}{79.8 - [100 - (\text{.....} + \text{.....})]} - \text{.....} \times \text{.....}$$

$$= \frac{\text{.....}[100 - \text{.....}]}{79.8 - [100 - \text{.....}]} - \text{.....}$$

$$= \frac{\text{.....} \times \text{.....}}{79.8 - \text{.....}} - \text{.....}$$

= ..... - ..... = ... - .....

= .....

Trial 3 $\%O_2$ = $\%CO_2$ =

$$RV = \frac{\text{.....}[100 - (\text{.....} + \text{.....})]}{79.8 - [100 - (\text{.....} + \text{.....})]} - \text{.....} \times \text{.....}$$

$$= \frac{\text{.....}[100 - \text{.....}]}{79.8 - [100 - \text{.....}]} - \text{.....}$$

$$= \frac{\text{.....} \times \text{.....}}{79.8 - \text{.....}} - \text{.....}$$

= ..... - ..... = ... - .....

= .....

Trial 4 $\%O_2$ = $\%CO_2$ =

RV = ...[100 - (..... + ...)] - ..... x .....
79.8 - [100 - (..... + ...)]

= .....[100 - .....] - .....
79.8 - [100 - .....]

= ..... x..... - .....
79.8 - .....

= ..... - ..... = ... - .....

= .....

Trial 5 $\%O_2$ = $\%CO_2$

RV = ...[100 - (.....+ .....)] - ..... x.....
79.8 - [100 - (..... + ...)]

= .....[100 - .....] - .....
79.8 - [100 - .....]

= .....x ..... - .....
79.8 - .....

..... - ..... = ... - .....

= .....

Mean RV of 2 trials within 100 ml = ... + ...

=

Observed body weight in water =

....

....

measured body weight in water (BWt_W) = ... kg

Body weight in air (BWt_A) = ... kg

RV = ... l

Volume of air in gastro-intestinal tract (V_{GI}) = 0.1 l

Temperature of water = ...°C

Volume of body (V_B) = $\frac{BWt_A - BWt_W - RV + V_{GI}}{D_W}$ (For D_W see table)

$V = \frac{..... - .....}{.....} - ..... + 0.1$

$= \frac{.....}{.....} - ..... = ... - .....$

= .....

body density (D_B) = $\frac{BWt}{V_B} = \frac{.....}{.....} = ...$

% fat (Siri) = $\frac{495}{D_B} - 450 = \frac{495}{.....} - 450$

=

BTPS - the body temperature pressure saturated correction factor which corrects the volume of measured gas to ambient conditions of the lung according to the following table:

Gas temp. (°C)	Correction factor	Gas temp. (°C)	Correction factor
20.0	1.102	24.0	1.079
20.5	1.099	24.5	1.077
21.0	1.096	25.0	1.074
21.5	1.093	25.5	1.071
22.0	1.091	26.0	1.069
22.5	1.089	26.5	1.065
23.0	1.085	27.0	1.062
23.5	1.082	27.5	1.060

WATER TEMPERATURE CORRECTION FACTOR - to give D_w

Water temp (°C)	Water density	Water temp (°C)	Water density
25.0	0.9971	33.0	0.9947
26.0	0.9968	34.0	0.9944
27.0	0.9965	35.0	0.9941
28.0	0.9963	36.0	0.9937
29.0	0.9960	37.0	0.9934
30.0	0.9957	38.0	0.9930
31.0	0.9954	39.0	0.9926
32.0	0.9950	40.0	0.9922

APPENDIX E

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